Escola Politècnica Superior d'Enginyeria de Vilanova i la Geltrú
UNIVERSITAT POLITÈCNICA DE CATALUNYA

TRABAJO FINAL DE GRADO

TÍTULO: Prototipo de palanca de gases (Throttle-HOTAS) para simulación aérea

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ABSTRACT

The throttle is a very important mechanism to control the thrust of the engines in the aviation world. From a little Cessna 172 to massive airbus 380 everyone uses it.

In this project using advanced technologies like CAD modeling, simulations and 3d printing, it will cover the most of the development process for a prototype.

From the initial concepts and ideas, test and experimentation to a physical prototype will be a large period of analysis, creativity and perseverance to make something from the scratch.

Development methodology will be an important feature for the success of the product.

Design → test→ analyze→resolve

In the market there are a lot of product with deficiencies in some aspects like non smooth axis and bad flight detents, the objective is to built the Throttle I always wanted to had.

The systems to design are:

-Stand→solid base for all the components

-Axis→allow smooth rotation

-Friction regulation→user can regulate the force needed to rotate the axis

-Flight detents→ throttle has some fixed positions

-Grip→ user interface (hand)

-Position control→ system to track and transmit the axis/ lever position

With the help of 3D printing, prototype will be manufactured, components will need to be tested and analyzed for a optimal functionality.

For a design structural optimization, using NX CAE (finite elements), a simulation model will be created and adjusted from physical test results.

With that model structural countermeasures can be analyzed before any physical prototype.

Keywords (Max.10)

Throttle	Development	Design	3D printer
Countermeasure	Aviation	Simulation	CAD-CAE

index

1.Motivation

As an enthusiast of the aviation, I am a user of flight simulators.

Study level Flight simulators give to me the closest look of how is to be a pilot and the technical knowledge of the flight dynamics and systems of every plane that I am interested to learn, from a huge commercial 737 to a fast and manoeuvrable F/A-18 Hornet.

Like a car the pilot has some elements that with his interaction can control the plane.

This element is practically the same on all the planes of the sky, from the cheapest to the latest technical advanced military jet.

The throttle is one of these elements and his function is to change the thrust that the engine applied to the plane, with that the pilot can proceed to control its speed in the air as in the ground.

From my experience, I want to design a throttle to comply the necessities and properties that I request from many years of flight simulation.

1.2 Objective of the project

The purpose of this Project is to design and built a prototype of a throttle for flight simulation.

As a user of flight simulators, I have observed that most throttles existing in the market have deficiencies in different aspects of their design in the axis mechanism that basically affect the precision of movement and the feeling of fluidity in the displacement and control compared to real flight professionals , other aspect to improve is the mechanism of the flight detents.

1.3 Specific Objectives

-Describe the control surfaces of a plane.

-Describes the throttle, types and functionality (real and sim) .

-Analyse and describe the mechanicals problems that I have with other products.

-Design with the program NX a throttle mechanism.

-Built a prototype with a PRUSA 3D printer and adjust them.

- Connect the throttle to the computer flight sim and complete his functionality using Arduino and a potentiometer.

- Develop model simulation for prediction of structural behaviour of a 3D Printed component.

1.4 Project methodology

First describe and analyse the throttles that are used in different real planes, analysed the actual sim throttle that are in the market.

Describe the properties of my prototype want to have.

Make the design with the NX program.

Built it with a PRUSA 3D printer and make a first adjustment. Use NX CAE to improve the design.

Program an Arduino with a potentiometer connected to the throttle for use the throttle in the PC flight sim environment.

2.Introduction

2.1 Throttle in the aviation

Before enter directly to the throttle system, the main actor of this project, first we need to understand the throttle like a piece of the machinery used by the pilot to control and govern the plane.

-HOW CAN THE PILOT CONTROL THE PLANE?

When a plane is flying on a mass of air, the machine is affected by some forces.

These forces generate a list of parameters and variables. Modifying and changing these flight variables provides the control of the plane.

For doing that the plane has a variety of systems which only mission is to modify the flight parameters.

At the same time these systems are governed with a set of controls (axis, levers, pedals), installed in the cockpit, the pilot can psychically interact with them. Is made by pilot hands and foots.

The way the information is sent from controls to the systems can be done by variety forms: mechanically, computational, etc.

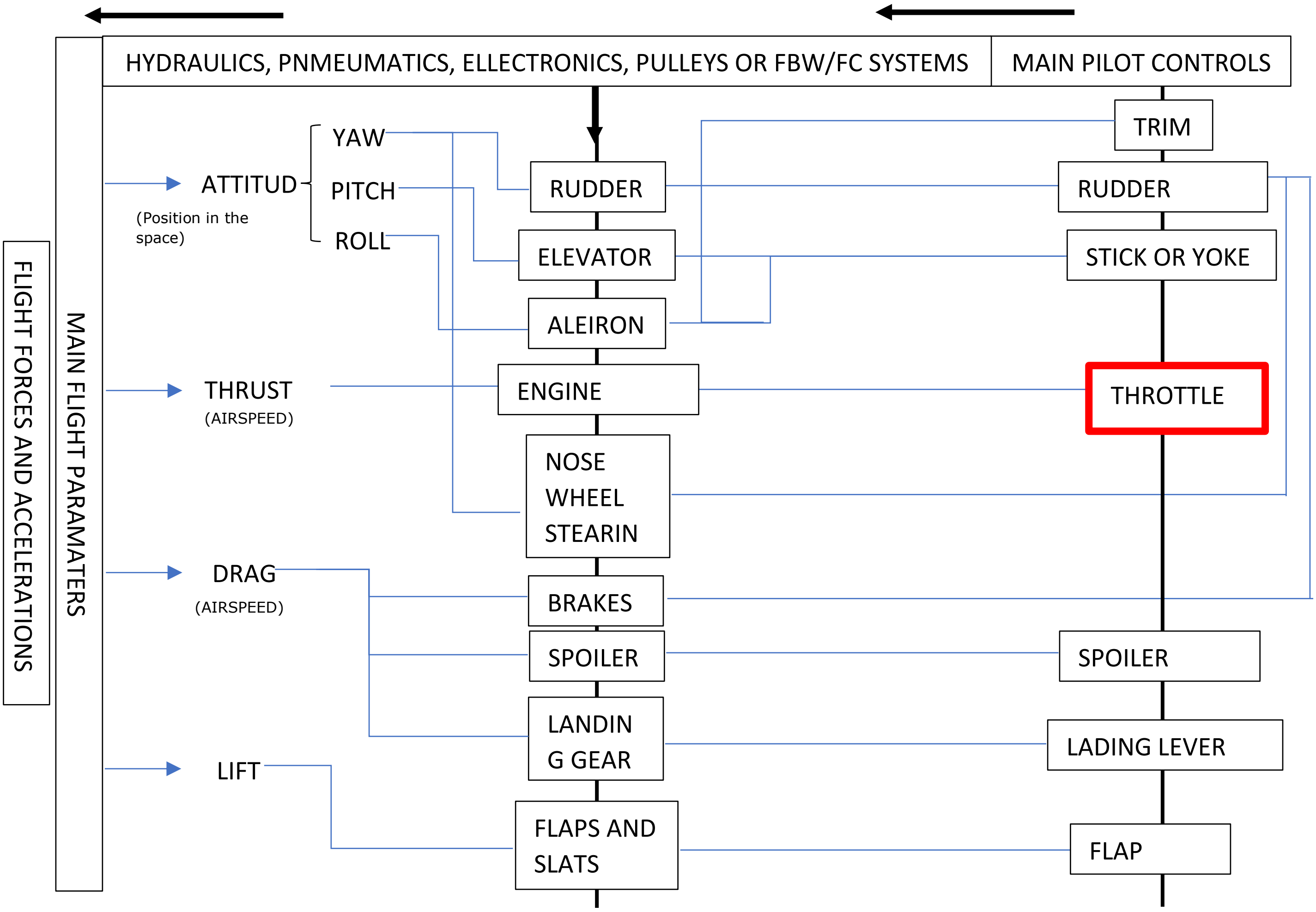


Fig.2.1 Scheme of Flight controls main pilot

The figure 2.1 identifies the flight controls of the main pilot and relates them to your flight system and the principal flight parameters that are affected.

Notice that this is only an overall look of the flight control system. There are a lot of interconnected flight parameters and the variation of one has impact to the others. The pilot needs to interact with all of them in harmony.

In general, in all of the planes of the world, the pilot uses 3 primary controls.

Primary controls

→Flight stick or yoke

→**Throttle**

→Rudder Pedals

→Trim for each one

The basic concept of the throttle or thrust levers is to manage the amount of thrust produced by the engines at any time with the movement of a lever, that movement can be linear or radial. Exist one throttle lever for each engine of the plane.

The position of the lever can be transmitted mechanically, hydraulically or electronically to the engine fuel control to increase or reduce the amount of fuel injected to the engine.

Exist a lot of types and design of throttles in aviation, but with and overview it can classify in 3 groups , described in the figure 2.2.

TYPE	Throttle Description	Throttle image
General aviation	→Linear movement push mechanism →Mechanically linked to a piston engine →No friction regulation → No flight detents →Simple design →Metal material	
Airliners	→Radial movement →Mechanically, hydraulically and electronically linked to turbofan engines →No friction regulation → Flight detents (flex, idle, max power) →Complex design and sensors →Metal material →Operation of the throttle can variate during different flight stages	
Military jets	→Radial or linear movement →Mechanically, hydraulically and electronically linked to turbofan engines with afterburner →No friction regulation → Flight detents for cut off, idle and afterburner →Complex design and sensors →Metal material →Operation of the throttle can variate during different flight stages	

Fig.2.2 Aviation throttles classification table

2.2 Overlook: real throttle system of an F14B

To understand the complexity of the throttle operation in a real plane like the F14B “the plane piloted by Tom cruise on TOP GUN film” let’s have and overview of the throttle system.

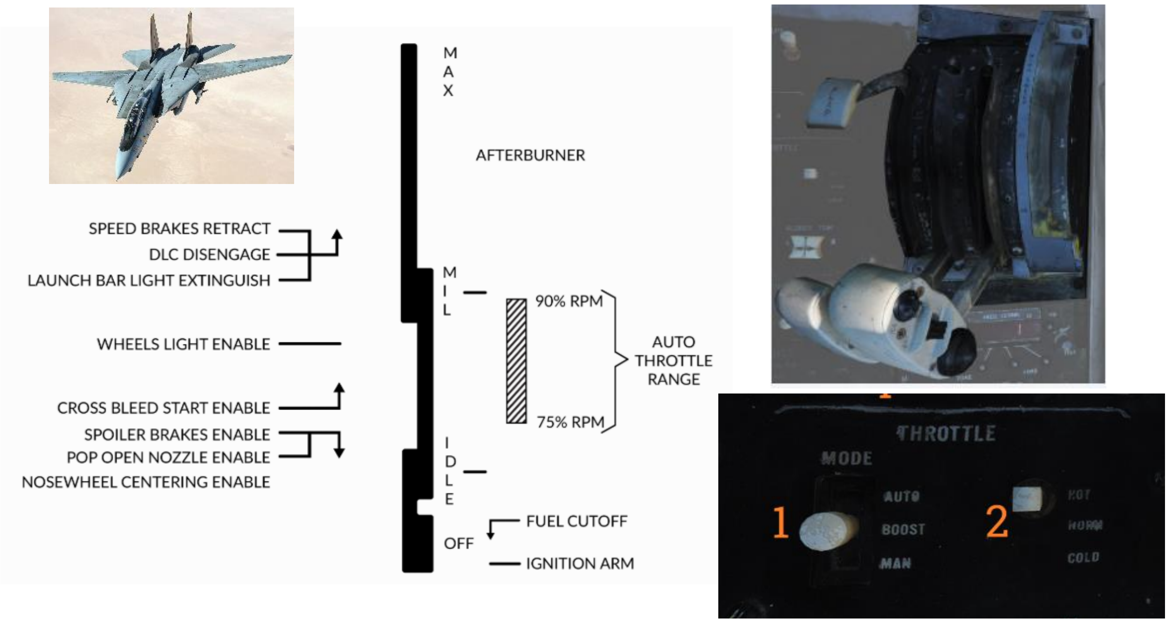


Fig.2.3 (left) diagram throttle operation, (right up) throttle quadrant image, (right down) Throttle mode switches image

The main throttle quadrant contains the two main-engine throttle controls (Figure 2.3 right up), the flap lever and manual wing-sweep handle in addition to the HOTAS controls on the throttles themselves. The throttles have detents in the OFF, IDLE and MIL positions.

Moving the throttles to the IDLE position from OFF (Figure 2.3 left) arms the ignition and disengages the fuel cutoff. The sideways movements of the throttles are not spring loaded, this is so the pilot can have the throttle resting at MIL power for catapult launches and prevents accidental spool down of the engines. A friction lever for selection of desired throttle movement friction is located on the left side of the throttle quadrant, beneath the flap lever.

The throttles in the F-14 have detents preventing unintentional engine start and shutdown and unintentional selection of afterburner. In addition, the throttles also control several different systems depending on throttle position as shown in the diagram above. The most critical of these being the fuel cut off and ignition systems in the respective engines.

For throttle operations there are three modes (Figure 2.3 right down (1)):

The manual mode is a mechanical mode in which the engines are controlled by mechanical linkages directly from the throttles to the engines. The manual mode is designed as a backup mode and may be inexact because of the mechanical nature of the controls.

Boost mode is the normal mode of operation in which electrical paths control actuators moving the same engine controls as the mechanical linkages but more exactly and with lesser force required.

The third mode is the approach power compensator mode or the auto throttle mode which is a system which allows for automatic throttle control for optimal angle-of-attack during approaches.

The controls for the throttle mode are located on the inlet ramps/throttle control panel to the side of the main throttles and allows for selection of all three modes. The auto throttle mode is solenoid held and will revert to boost mode if the criteria for automatic controls are not met.

To allow selection of auto mode the throttles need to be between 75 to 90% rpm, the gear handle needs to be down and with no weight on the wheels. If these criteria are no longer met, the throttles are manually overridden with force or the Cage/SEAM button on the left throttle is depressed the solenoid releases the switch and it reverts to boost.

For additional auto throttle tune the gain of the system (Figure 2.3 right down (2)) can be set on the inlet ramps/throttle control panel. The settings are hot, normal or cold with hot increasing the throttle gain (and effective thrust) and cold decreasing it. These settings correspond to cold or hot external temperatures but should be set according to observed throttle control.

So, in real aviation the throttle lever is a very complex mechanism and their control multitude of system, valves to manage the engine.

2.3 Throttle in the simulation aviation

Simulation business throttles are used for pilots or simulation enthusiast to simulate the capabilities of the real throttles. In the non-professional simulation spectrum, the throttle only transmits their position via a potentiometer, and that signal is transmitted to a computer. Using an aviation simulator, users can map that movement to the program and transmit it. The program can use that signal to simulate the system as a real throttle is operated.

Real throttles cost is thousands of dollars, but in general aviation simulation, that cost is hundreds of dollars due their simpler mechanism and materials.

2.4 Product in the market analysis

In market exist different products to cover the mayor types of airplanes, from basics throttles to a high end for the most real experience in the Figure 2.4 the advantages and shortcomings of the most popular are shown..

Product	Picture	Positive	Negative
Logitech Throttle quadrant		→3 levers (axis) →desk mount →General aviation →small grip →Low cost → Radial movement → No HOTAS →Plug & Play	→No flight detent →Plastic material →Low friction, no adjustable →Plastic Axis with lubricant →Low weight, fragile
CH Pro throttle		→1 Lever →HOTAS →Linear movement →Military aviation →Plug & Play →Low cost	→No flight detent →Plastic material →Low friction, no adjustable →Plastic Axis with lubricant →Low weight, fragile

Product	Picture	Positive	Negative
Thrustmaster TWCS		→1 Lever →HOTAS →Linear movement →Plug & Play →Intermediate cost	→No flight detent →Plastic material →Low friction, no adjustable →Plastic Axis with lubricant →Low weight, fragile
Thrustmaster Warthog		→2 Levers →HOTAS →Radial movement →Flight detents removable →Up & Push flight detent →Smooth feeling →Replica →Robust →Metal design →Robust flight detent system	→ Replica of a real military jet difficult to use in general aviation →high travel of the lever →Big grip →Expensive →Difficulty to remove flight detents → No adjustable flight detent
Virpil Mongos T50		→2 Levers →HOTAS →Radial movement →Flight detents adjustable →Push flight detent →Smooth feeling →Robust →Metal design →Extra Buttons →Friction adjustable	→Difficulty to regulate friction (tool required) →Easy to skip flight detent position →Expensive →Low travel →Bad lever position (not centered)

Fig.2.4 Market Throttles comparison table

2.5 Throttle Analysis Conclusions

After analyse the products on the market, I can classify them in 2 types:

→**<u>The low-end products</u>**: cheap coast, basic functionalities, poor mechanism and plastic manufactured. It suffers low quality feeling by the costumer.

→**<u>High end products:</u>** built with more functionalities trying to simulate as much as possible the real ones. The material used is metal resulting a more robust product and better feelings for the costumer.

3.Prototype development methodology

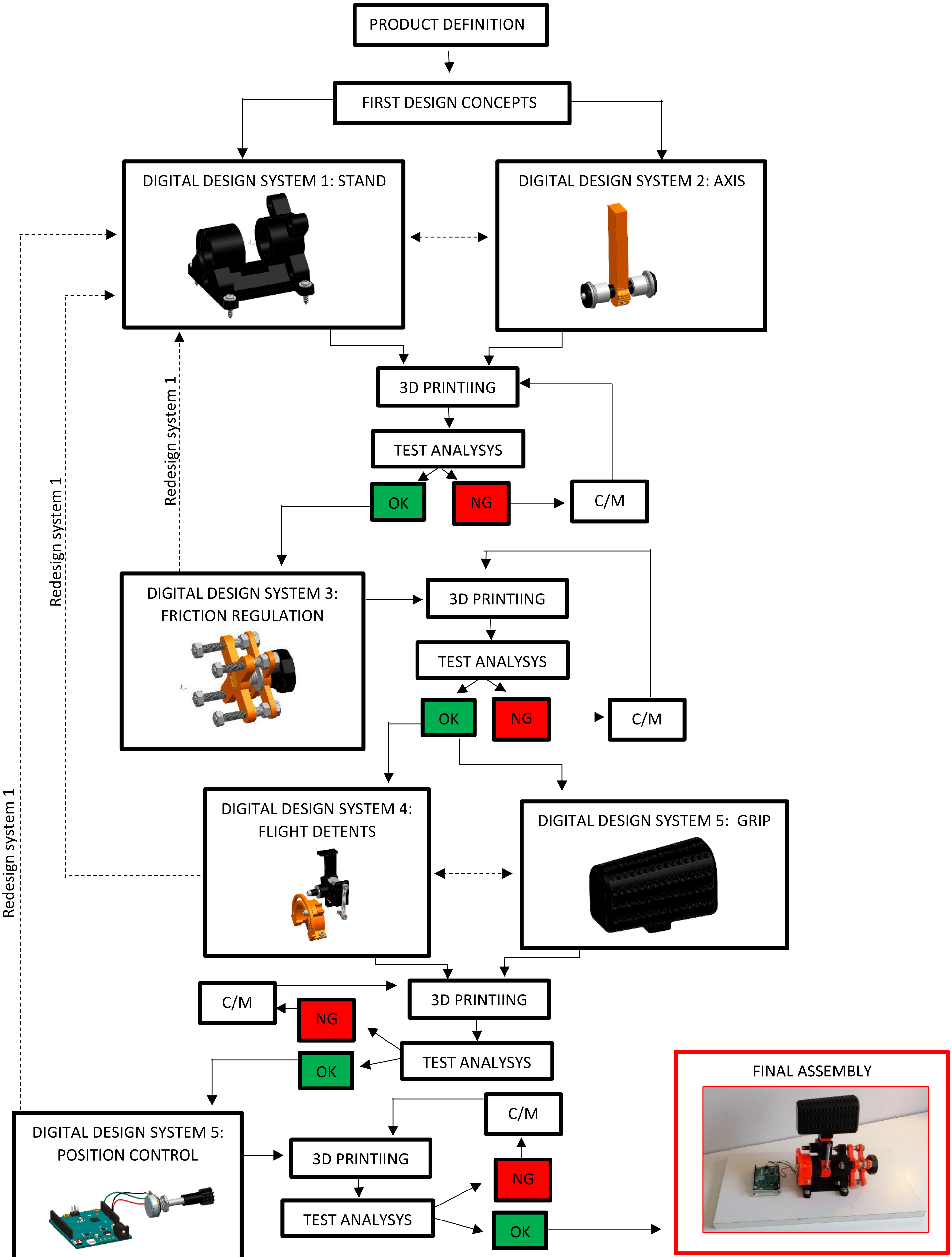


Fig.3.1 Throttle development methodology diagram

The begging of the development process (Production definition in figure 3.1) is needed to define what it wants to do, how it will do it and how this decision affects the design requirements.

3.1 PRODUCT DEFINITION

-User functionality

-Performance target

-Number of systems

↓

3.2 DESIGN AND PROTO PRODUCTION TOOLS DEFINITION

-Digital design software→NX12

-Material and proto production process (feasibility)→3D PRINTER PETG

-Supplier components→ (BOLTS, NUTS, ROLLING BEARINGS, SPRINGS)

↓

3.3 OTHER DESIGN REQUIREMENTS

-Durability

-Workability and Serviceability

-Appearance

Fig.3.2 Product definition diagram

3.1 Product definition

After many years involved in the aviation simulation, It was easy to define the characteristics, systems and functionality.

The throttle would have the following functionalities, characteristics and properties:

1-The axis movement needs to be smooth with a fluid movement, for achieve that it will be used rolling bearings.

2-Force needed to move the throttle can be regulated via friction mechanism, user can regulate it via easy movement with one hand (user friendly).

3-Minimum throttle movement will be 90 degrees.

5-Throttle will have a flight detents mechanism with user adjustable stops and positioning.

6-Throttle will have an ergonomic grip with anti-skid surface

7-Throttle position can be read with the more common flight simulations that will be achieve with a potentiometer linked to the lever with a gear mechanism.

Potentiometer will be connected to an Arduino board; it will convert the analogue signal to digital. That will allow windows to read its position.

8-Throttle needs to be compact for use on desk table.

To achieve all these requirements, it will be developed 6 systems each one responsible to achieve each functionality (system and functionalities shown in figure 4.3).

S. DES.	SYSTEM	FUNCTIONALITY
1.1	STAND	Base for all the systems
1.2	AXIS	Provide fluid movement to the lever
1.3	FRICTION REGULATION	User-adjustable movement force
1.4	FILGHT DETENTS	Adjustable Flight detents
1.5	GRIP	Ergonomic grip
1.6	POSITION CONTROL	Functional with PC flight simulators

Fig.3.3 System functionalities table

3.2 Design and prototype production tools definition

→Digital phase

The digital design phase will be developed via the software NX 12(fig. 3.4).

Fig.3.4 CAD-CAE software Siemens NX logo

Why NX12?

NX is an advanced high-end CAD/CAM/CAE develop by Siemens destined to engineers, designers to develop their products.

It is a powerful tool that I use in my job. It allows a lot of possibilities; from developing the modelling to analyse them via a CAE simulation.

I select this software because of my “know how” of it and its power.

The product will be design in assembly context and another module that will be use is the CAE Advanced simulation for study the mechanical properties and behaviours of some pieces.

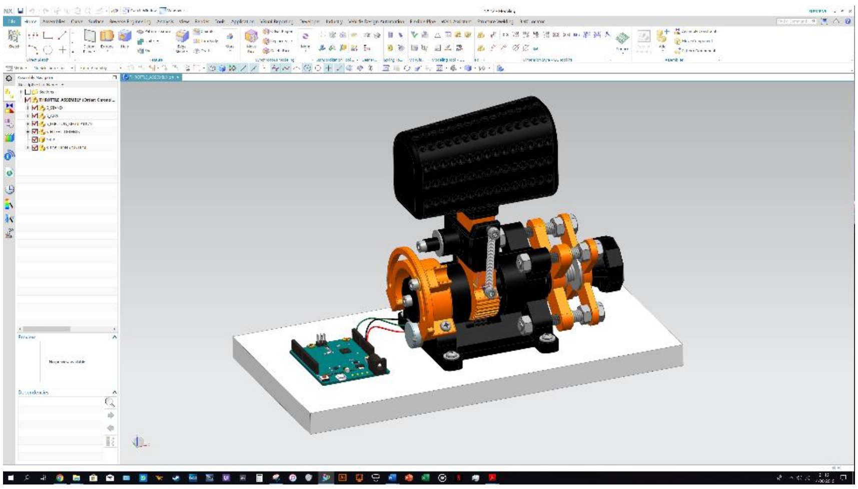


Fig.3.5 Screenshot of the throttle 3D model with NX software environment

→Prototype manufacturing phase

Due the time, cost and feasibility it was decided to use a 3D printer for produce the prototype.

I acquired a PRUSA MK3 3d printer.

Why PRUSA MK3?

PRUSA 3D printers are the most used in the world (non-professional), uses free code and the most important, uses an automatic calibration for start printing, this characteristic earns a lot of time and effort due the number of designed pieces in the project.

I acquired the PRUSA not assembled. It took me 2 weeks for the assembly. It was a great opportunity for understand the machine functionality, components design and tricks used by PRUSA engineers using their own 3d plastic material.

I would use some of these tricks to my own design.

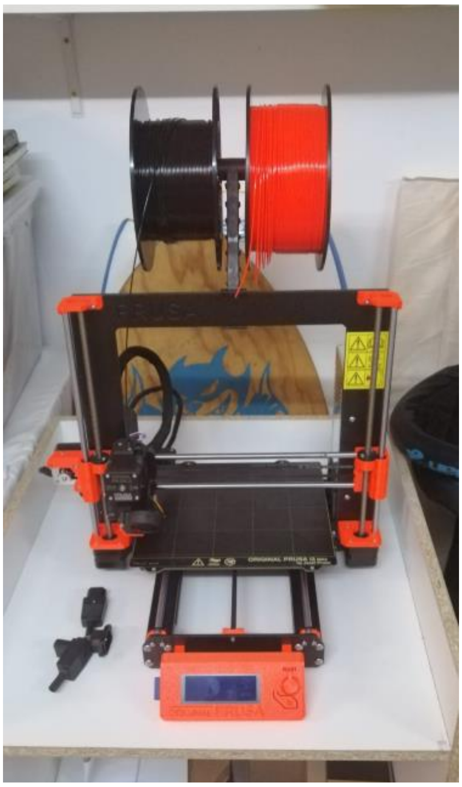


Fig.3.6 Own Prusa mk3 model image

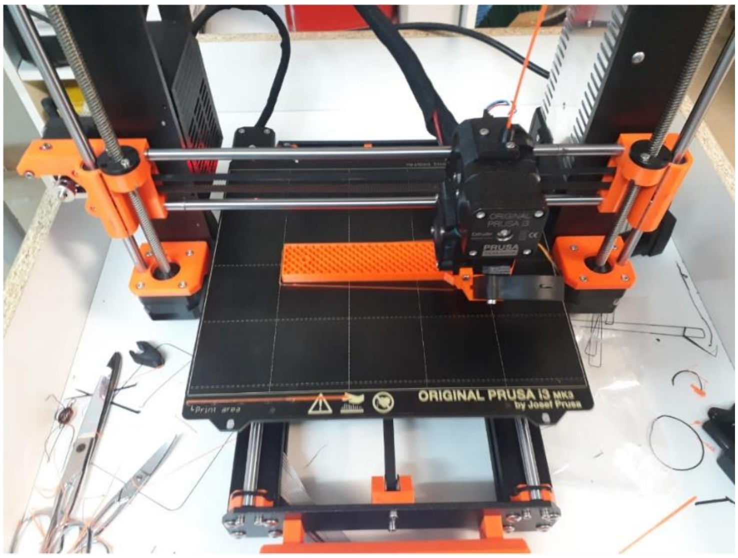


Fig.3.7 Prusa mk3 model printing component lever image

The PRUSA MK3 uses GCODE files information to print the models.

To translate the NX files to GCODE, PRUSA provides PRUSA CONTROL software.

This software is user friendly with most of print parameters suitable for their 3D printers.

Software demand STL files from CAD models so it's needed to translate with the NX environment from PAR to STL files.

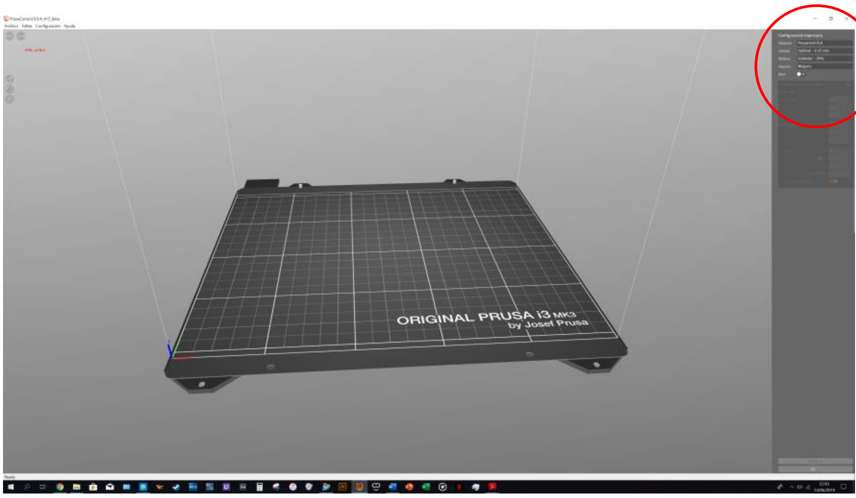


Fig.3.7 Screenshot Prusa software

Fig.3.8 Prusa software parameters detail

Once the STL files is imported to the software, we can adjust the position of the model and the following printing parameters (fig. 3.8 & 3.9).

Parameter	Description
Material	Selects between the different materials
Quality	Selects the quality of the print, ↑quality↑ printing time /from 0.05 to 2 mm
Filling	Select quantity of material for the solid parts / from 0% to 70%
Support	Selects supports to achieve printing of certain 3d models
Brim	Makes a base of material for better fastening

Fig.3.9 Parameters description table

When the GCODE is generated by the software we can save that info in a SD card and print it directly in our PRUSA.

Due my 3D printing experience I realized the importance of correct first layer print. It is necessary to stay and wait for the correct printing, in some cases it will take some parameters adjustment like extrusion / bed temperature or velocity time.

→Material

According it's properties I decided to use PET G material for the prototype manufacture.

PRUSA manufacture inform on their web:

"PETG is a very tough material with good thermal resistance. It is a universal material, but it's especially suitable for mechanical parts and both indoor and outdoor use. PETG has almost no warping, so printing large objects isn't a problem. We use PETG to print parts for our printers!

PETG is one of our favourite materials for 3D printing. It's almost as easy to print as PLA, but it can offer many mechanical properties that PLA prints just cannot achieve. The G in the acronym PETG stands for Glycol which is added during the manufacturing

process. Glycol modifies the properties of PET, so that it's easier to print, less brittle and clearer when printing with semi-transparent variants. PETG has low thermal expansion, so even when printing big objects, and without an enclosure, it rarely lifts from the bed and warps.

In addition to that, PETG is ductile. It has a healthy amount of flex which can prevent parts from breaking under pressure"

So, PET G is a cheap material, resistant and has good properties for a mechanical use.

And it's the material that PRUSA uses to build their own 3D printers.

→3D printing design requirements (feasibility)

The prototype manufacture material will be PETG from a 3D printer. The design needs to adapt to material and the manufacture process requirement.

Principal considerations for the components design in the project:

1-It will try to not use supports or Brim, this can be achieved by:

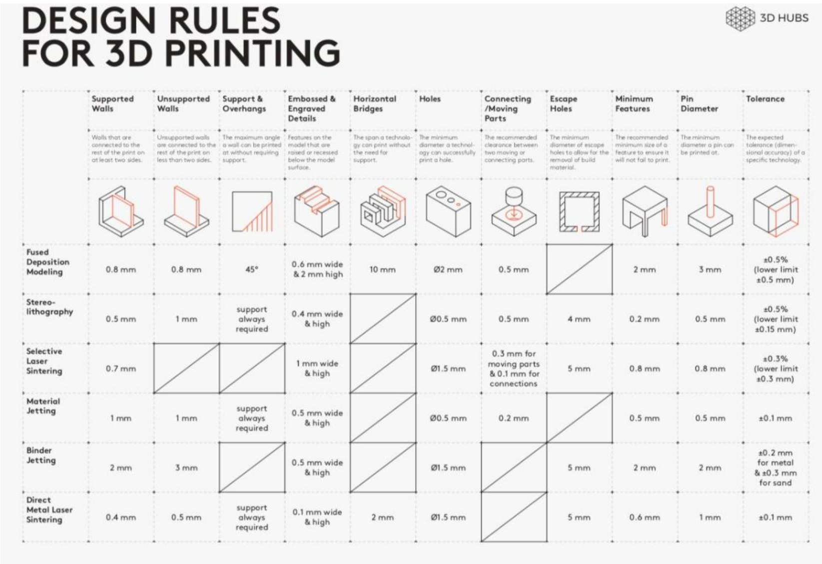
→One side of the component will be planar

→There will not be bridged parts, all components sections need to rest with material.

2-Plastic thread is difficult to print, use a metal nut and make some allocation in the plastic component (fig 3.10).

In general, most of the design requirements requested for the 3d printer are learned with the experience and experimentation of the limits of each individual printer.

Fig.3.10 Nut location design 3D model image



DESIGN RULES FOR 3D PRINTING

3D HUBS

	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

Fig.3.11 Design rules table

→Supplier components

In the beginning of the project, all the standardized components must be selected and acquired.

The standard components will be (bolts, nuts, washers, bearings, springs, potentiometers, etc.)

In general, this rule will be followed: the plastic components should be designed to adapt the standardized components.

→Tolerances

Tolerances will be adjusted experimentally, the general tolerance rule will be ISO 2768-m.

3.3 Other design requirements

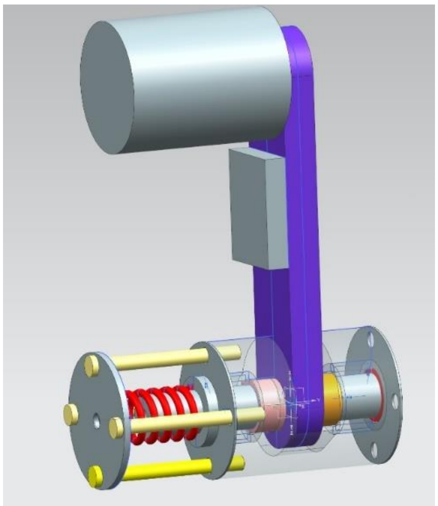
The components have to be designed for a good durability point of view (with reinforcements if is needed) and for a good appearance (it will be using a combination of orange and black colours for the plastic components).

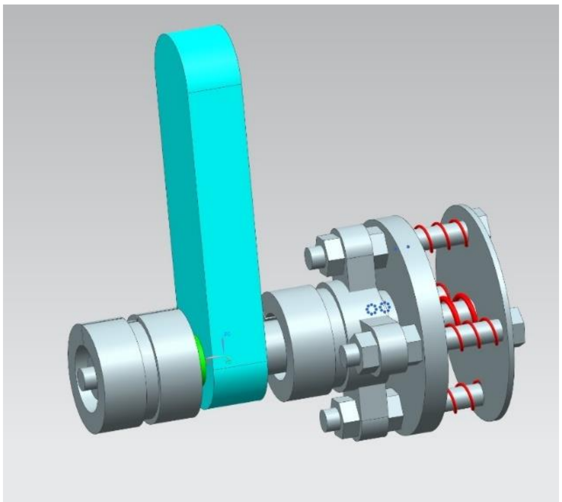
3.4 Porotype design and manufacture

Once the product is defined, it can start with de design and manufacture phases. Most of the performance of the throttle is judged by personal perception of it. This is why, it was decided to develop the project by experimentation (try and failure). Later, it can extract data of the prototype to adjust the design for a next version.

3.5 Firsts design concepts

First off all, I made some sketches and quickly assemblies on NX to understand the complexity of the systems and how it needs to be the designed (fig 3.12).





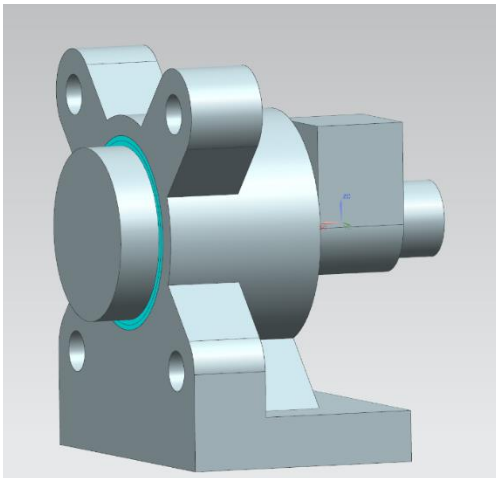


Fig.3.12 first designs concepts images

3.6 Design and manufacture

The process will be considering design and construction at the same level (see diagram fig.3.1).

Projects starts with the digital design of the system 1 (STAND) parallel to the system 2 (AXIS), each one is affected by the other one.

Once the design of the two system is completed, it will be proceeded with the printing of all the components of these 2 systems.

The next step is testing the systems. This test will consist on:

-Check mechanical resistance

-Assembly the parts

-Check functionality

After the test, the systems will be judged and declared OK or NG, judgment criteria is defined by the experimentation.

If it is NO GOOD, it will be studied which component is causing the issue, study it and apply countermeasure to solve it.

The countermeasures can be of the following types:

-Post process measure (example file the edges)

-Modification of 3D printing parameters such percentage of filling or detail.

-Design / layout modifications

Once the C/M is applied it will be tested again and judged again.

If it is declared OK, the design will advance to the next system number 3 (FRICTION REGULATION) and the process will be repeated assembly that system to the previously assembled (1 & 2).

The design of the system 3 can represent design modification for the system 1.

When the system (3) is judged OK the next step will be the system 4 (FLIGHT DETENTS) and (GRIP) on parallel.

And then it will be respited for the system 5 (POSITION CONTROL).

Finally, this process will finish with the throttle assembled with all the components tested and judged OK.

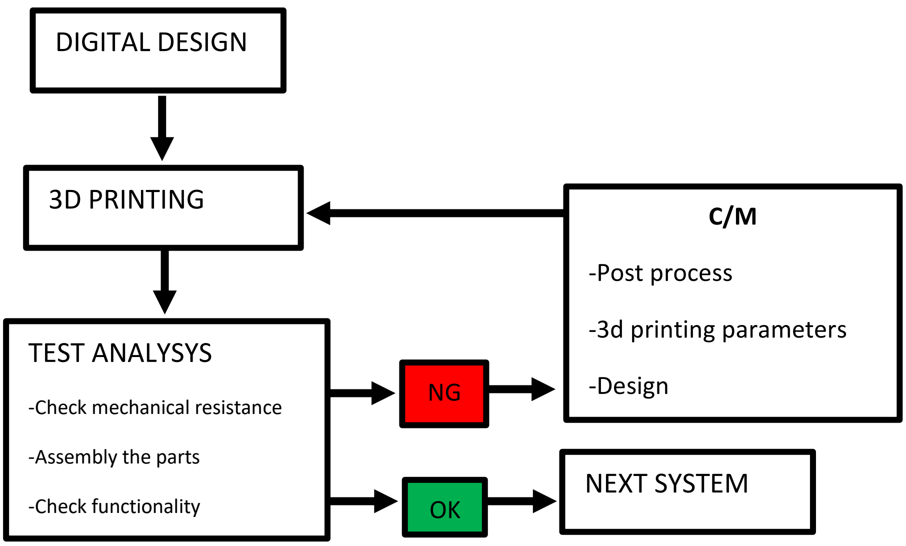


Fig.3.13 Generic development process for all systems

4.0 Assembly development sheet

TOP ASSY SPEC LIST SUMMARY

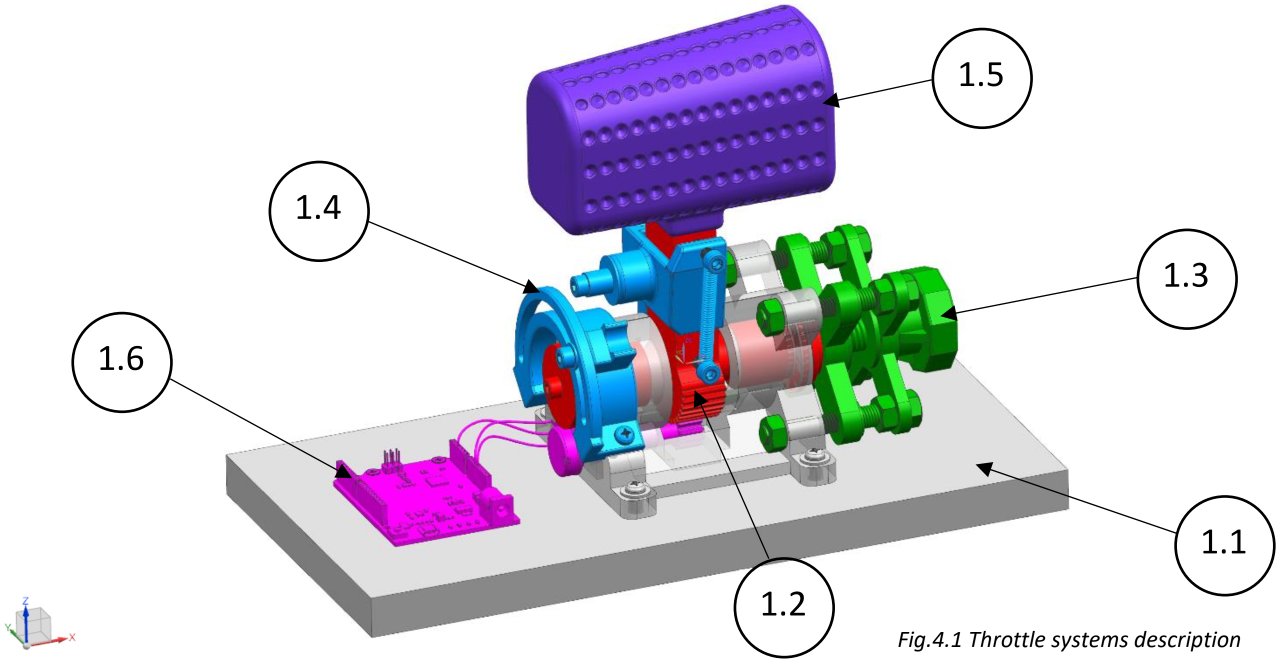


Fig.4.1 Throttle systems description

			Systems description		P/N	General function	Mass	CAD DATA
1	Throttle full Assy				A100	User Input for engine power		THROTTLE_ASSEMBLY.prt
		(grey)	1.1	Stand	S110	Base for all the systems		S_STAND.prt
		(red)	1.2	Axis	S120	Provide fluid movement		S_AXIS.prt
		(green)	1.3	Friction regulation	S130	User-adjustable movement force		S_FRICTION_REGULATION.prt
		(blue)	1.4	Flight detents	S140	Regulable movement detents		S_FLIGHT_DETENTS.prt
		(purple)	1.5	Grip	S150	Ergonomic grip		S_GRIP.prt
		(magenta)	1.6	Position control	S160	Measurement of the lever position		S_POSITION_CONTROL.prt

PERFORMANCE TARGET				
1	Throttle full Assy			Compact for be used with a table desk
		1.1	Stand	Strong and stable to provide a solid base for the rest of the components
		1.2	Axis	Smooth movement, robust feeling
		1.3	Friction regulation	Movement force regulation user preference, robust feeling
		1.4	Flight detents	Viability to use various flight detents for any aircraft type, regulable position
		1.5	Grip	Ergonomic geometry
		1.6	Position control	Viability to connect to a PC and use it with simulators, Plug & Play

DESIGN REQUIREMENTS
DURABILITY
By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality
FESEABILITY
Prototype it is made with a Prusa 3D printer, the design is made thinking on the constrains of this productive method.
WORKABILITY AND SERVICEABILITY
The assembly or disassembly of the component has to be allowed during the life of the product.

CAD

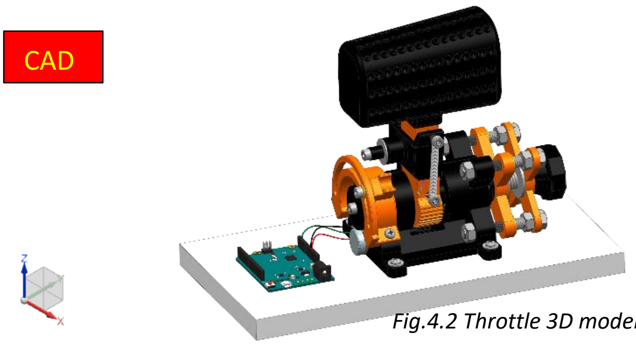


Fig.4.2 Throttle 3D model image

PROTO

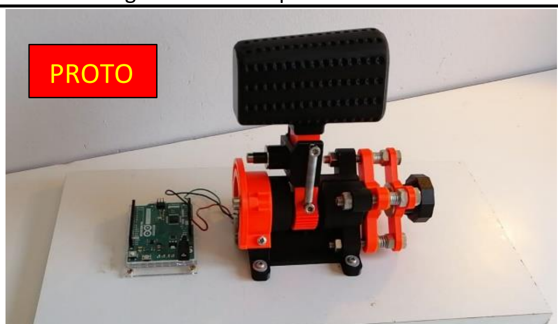
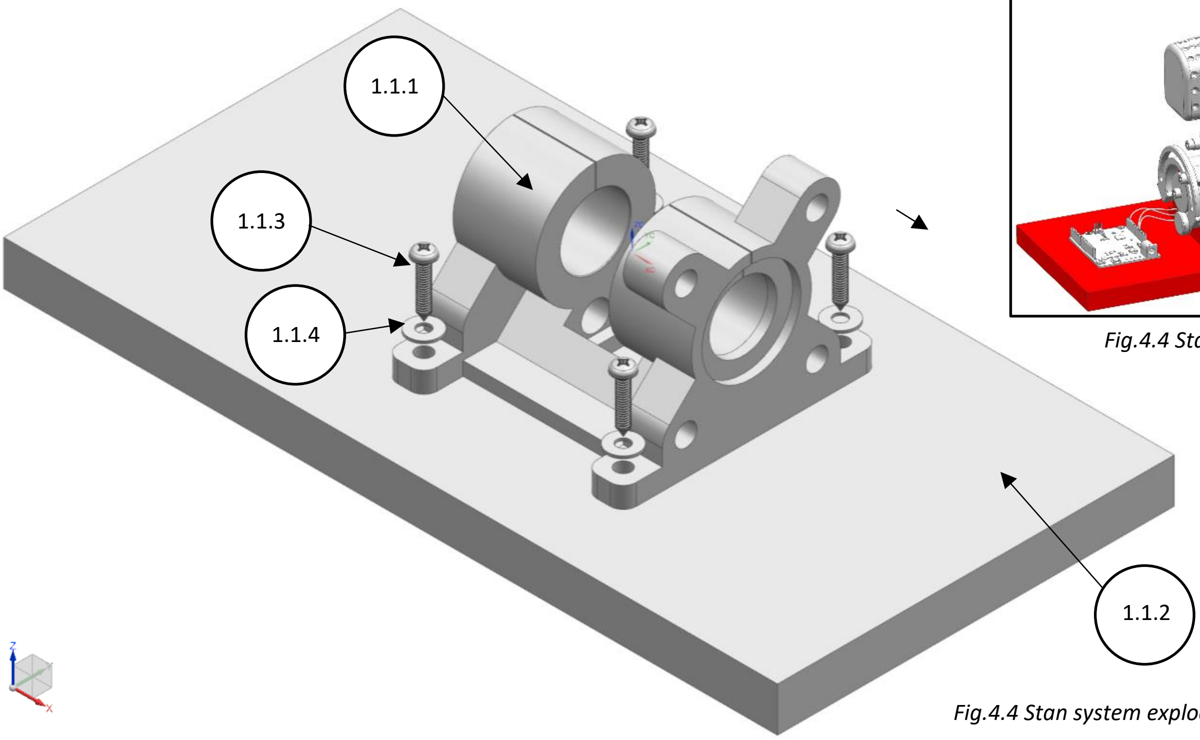


Fig.4.3 Throttle proto image

4.1 System S100 stand development sheet

SYS 1.1 STAND								



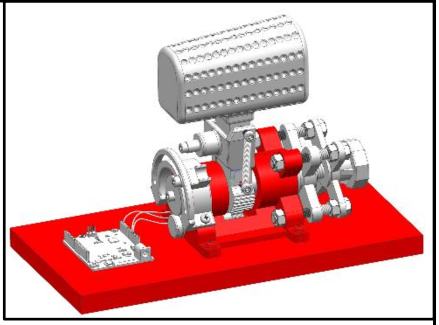


Fig.4.4 Stand system situation

Fig.4.4 Stan system exploded view

		Component description		P/N	General dimensions	Material	Mass	CAD DATA
1.1	Stand			S100				S_STAND.prt
		1.1.1	Body	C101	91.4x98.20x77.93	PET G		BODY.prt
		1.1.2	Floor plate	C102	296.5x152x17	Wood		FLOOR_PLATE.prt
		1.1.3	X4 Screw M5x20	C103	M5x20	Steel		SCREW_M5X20.prt
		1.1.4	X4 Washer	C104	Ø5xØ12x1	Steel		WASHER_SCREW_BAASE.prt

FUNCTIONALITY
To accommodate all system and components of the throttle, providing a solid base for the optimal functionality to all of them.
TARGET PERFORMANCE
Strong and stable to provide a solid base for the rest of the components
DESIGN REQUIREMENTS
DURABILITY
By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality
FESEABILITY
Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.
WORKABILITY AND SERVICEABILITY
The assembly or disassembly of the component has to be allowed during the life of the product.

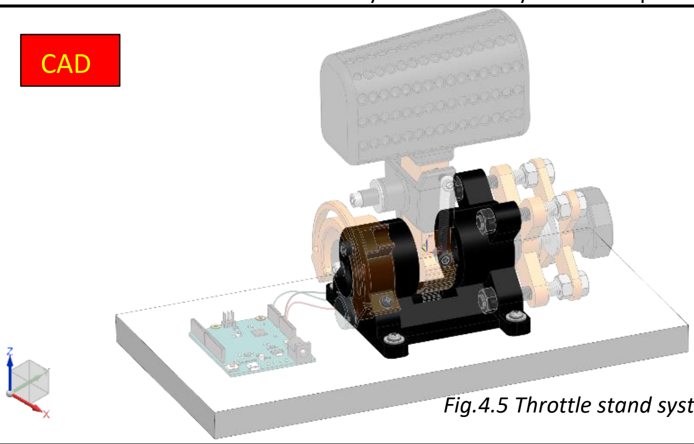


Fig.4.5 Throttle stand system

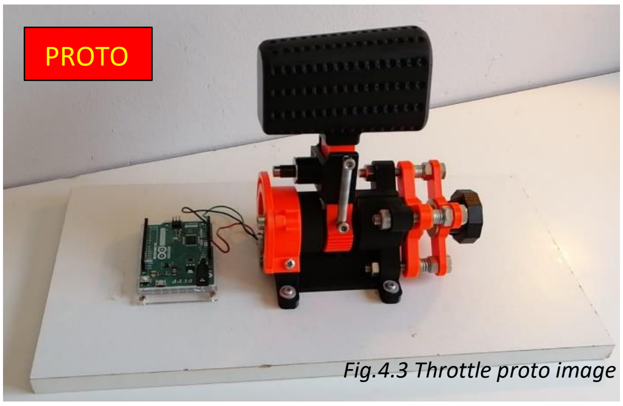


Fig.4.3 Throttle proto image

4.1.1 Component C111 Body development sheet

REF	P/N	DESCRIPTION
1.1.1	C111	BODY

GEOMETRY OVERVIEW

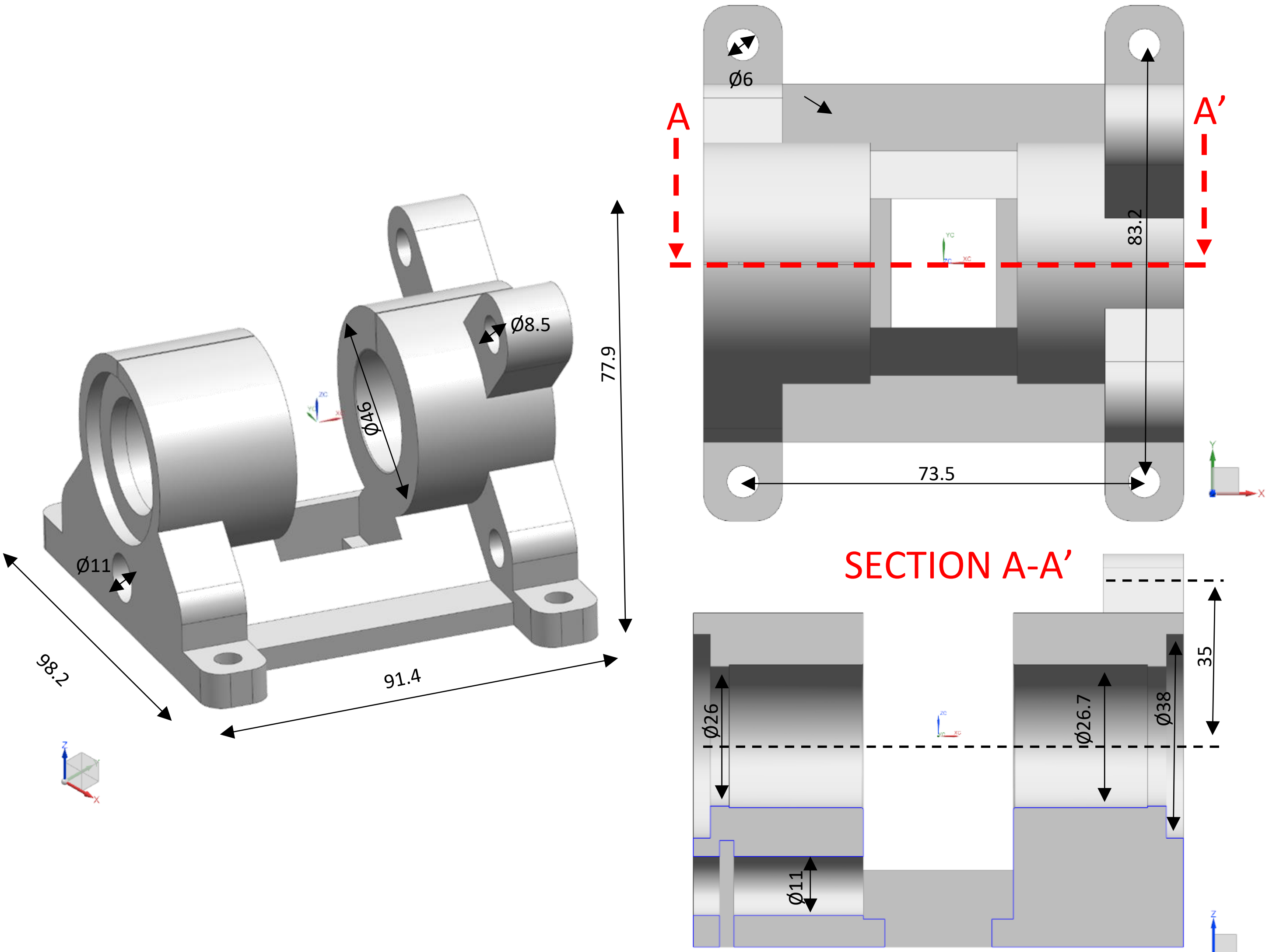


Fig.4.6 C111 Component model views

FUNCTIONALITY

To accommodate all system and components of the throttle, providing a solid base for the optimal functionality to all of them.
Provide allocation for radial/axial bearings, potentiometer, and screws.
Provide a solid bench for the friction regulation system

SPECIFIC COMPONENT DESIGN REQUIREMENT

DURABILITY	Needs to be compact, strong and stable to provide a solid base for the rest of the components. By durability point of view, this component has the worst condition, is subjected a lot of stress by the forces provided by the others systems. Needs to be resistant and rigid.
FESEABILITY	Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.

REF	P/N	DESCRIPTION
1.1.1	C111	BODY

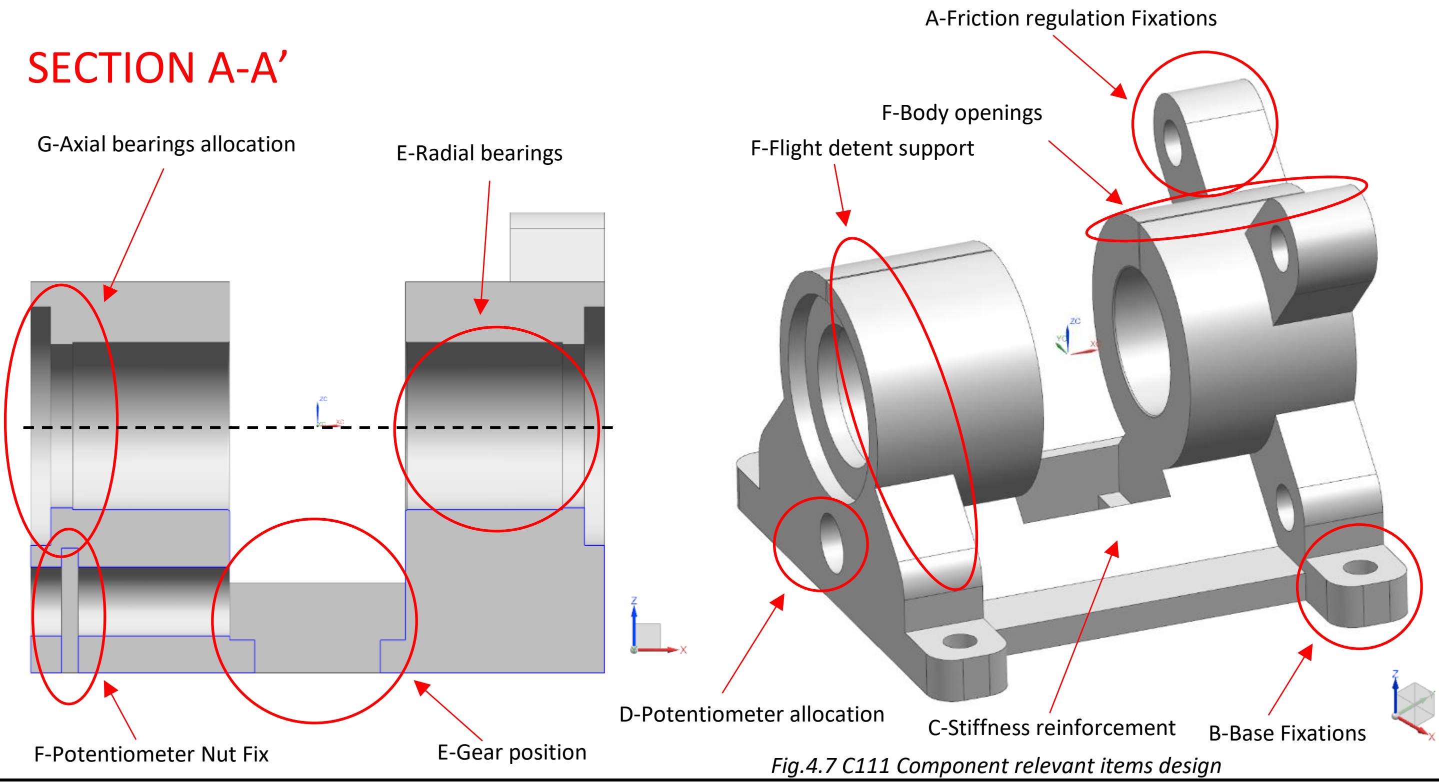


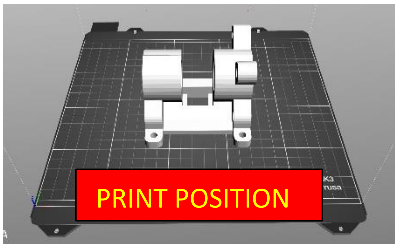
Fig.4.7 C111 Component relevant items design

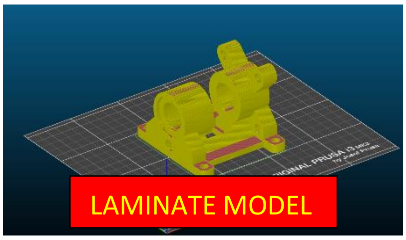
RELEVANT DESIGN ITEMS

REF.	DESCRIPTION	ASSOCIATED SYSTEM
A	Bench for the friction regulation 4x M8 bolts	1.3 Friction regulation
B	Base fixations with the Floor plate	1.1 Stand
C	Reinforcement to achieve stiffness	1.1 Stand
D	Allocation for the potentiometer	1.6 Position control
E	Clearance for the potentiometer Gear	1.6 Position control
F	Allocation for the fixation (Nut) of the potentiometer	1.6 Position control
G	Allocation for the axial bearings	1.2 Axis
E	Allocation for the radial bearings	1.2 Axis
F	Support for the flight detent guide	1.4 Flight detents
G	Body openings to ensure Bearing fixation due 3d print tolerances (clamp functionality)	1.2 Axis

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	BODY.stl	BODY.gcode

POS.		ROTATION
X	0	0
Y	0	0
Z	0	0





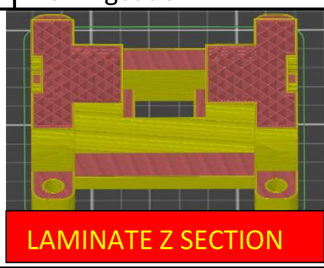


Fig.4.8 C111 Component Prusa 3D printer model views (position, laminate model, laminate section)

REF	P/N	DESCRIPTION
1.1.1	C111	BODY

RELEVANT DEVELOPMENT HISTORY

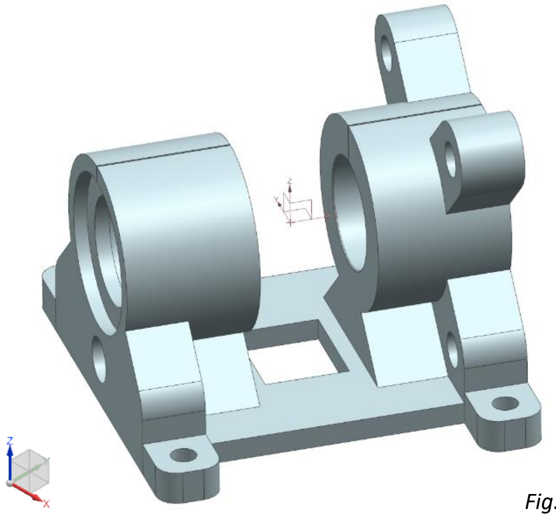


Fig.4.6 C111 Component model views

LEGACY DESIGN

LEGACY PROTO MANUFACTURE PARAMETERS

3D printer model	Material	QUALITY	FILLING	BASES
PRUSA MK3	PET G	0.15mm	20%	NO

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
Durability and strength	NG	Axis force (compression) causes high deformation on X direction	Place reinforcements to improve stiffness	OK
Functionality	OK	-	N/A	N/A
Workability and serviceability	OK	-	N/A	N/A
Aspect	OK	-	N/A	N/A

TEST RESULTS IMAGE	C/M IMAGE

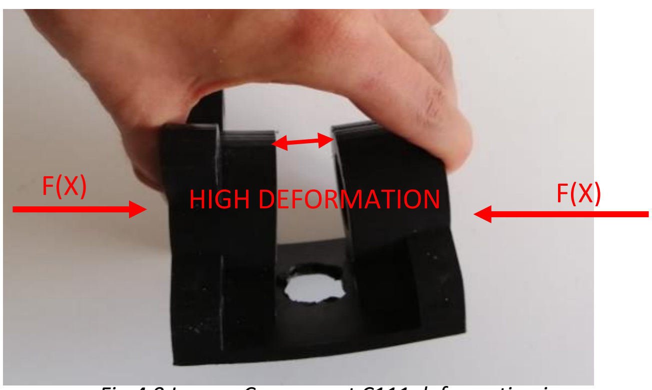


Fig.4.9 Legacy Component C111 deformation image

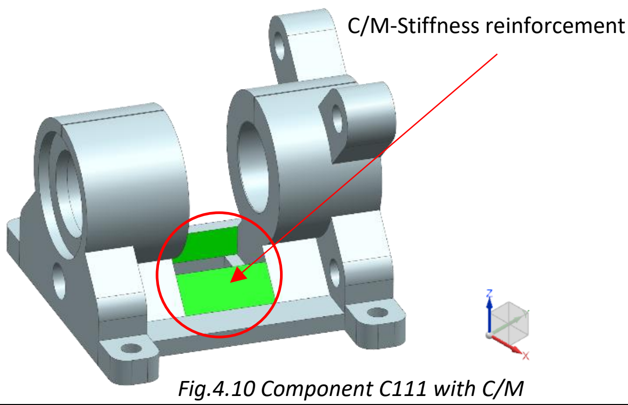


Fig.4.10 Component C111 with C/M

4.2 System S120 axis development sheet

SYS 1.2 Axis

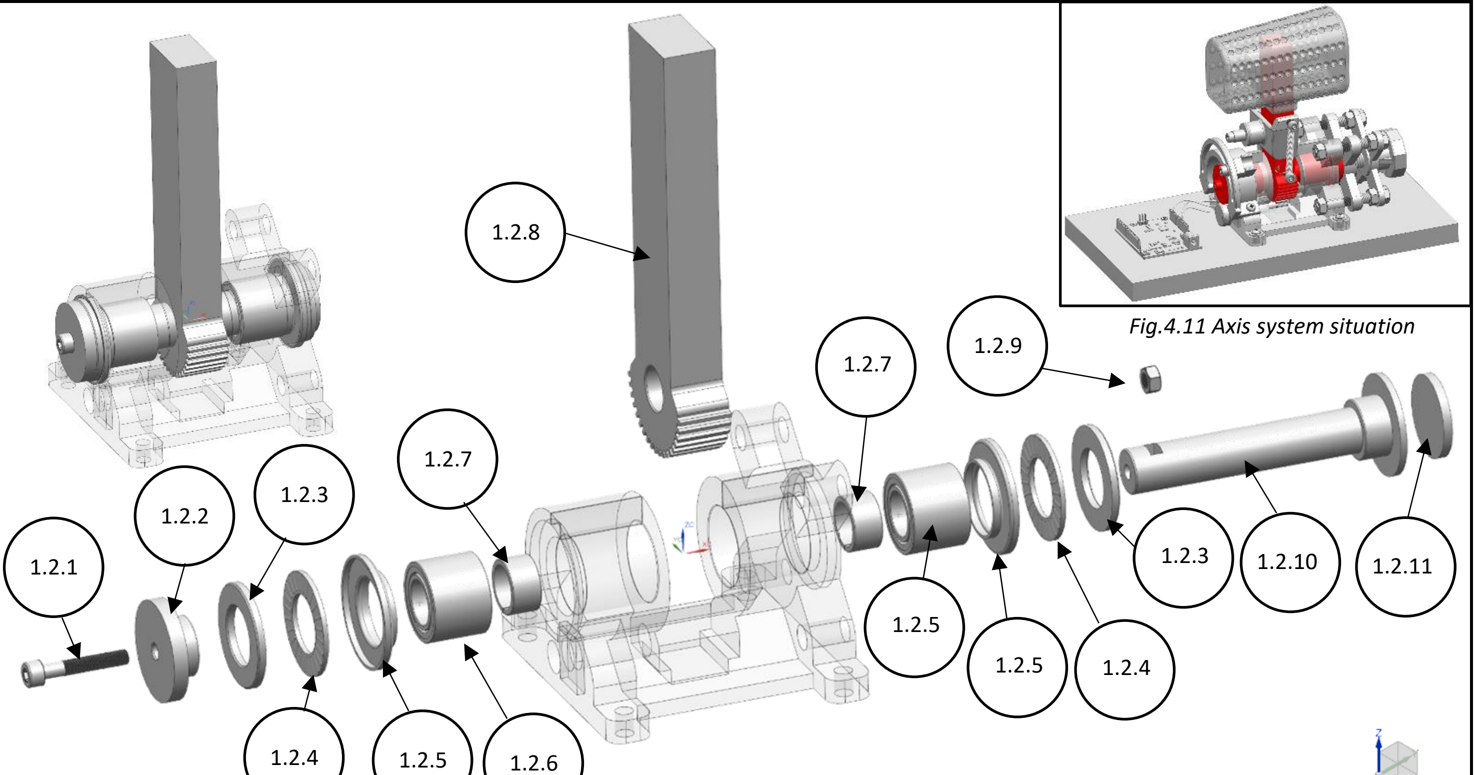


Fig.4.11 Axis system situation

Fig.4.12 Axis system exploded view

		Component description		P/N	General dimensions	Material	Mass	CAD DATA
1.2	Axis			S120				S_AXIS.prt
		1.2.1	Bolt M5X30	C121	M5X30	Steel		TOP_AXIS.prt
		1.2.2	Top Axis	C122	Ø34X11.7	PET G		WASHER_AXIAL_BEARING.prt
		1.2.3	Washer axial bearing	C123	Ø20XØ35X2.75	Steel		WASHER_AXIAL_BEARING.prt
		1.2.4	Axial Bearing	C124	Ø35X2	Steel		AXIAL_BEARING.prt
		1.2.5	Jail Axis Bearing	C125	Ø38X6.5	Steel		JAIL_AXIS_BEARING.prt
		1.2.6	Radial Bearing	C126	Ø27X20	Steel		RADIAL_BEARING.prt
		1.2.7	Cap Axis	C127	Ø18.7X10	PET G		CAP_LEVER.prt
		1.2.8	Lever	C128	145.56X30x18	PET G		LEVER.prt
		1.2.9	Nut M5	C129	M5X8X4	Steel		NUT_M5.prt
		1.2.10	Axis	C1210	Ø15X90.7	PET G		AXIS.prt
		1.2.11	Brake disc	C1211	Ø28X90.7	Fibres		BRAKE_DISC.prt

FUNCTIONALITY

Provide fluid movement

TARGET PERFORMANCE

Smooth movement, robust feeling

DESIGN REQUIREMENTS

DURABILITY

By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality

FESEABILITY

Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.

WORKABILITY AND SERVICEABILITY

The assembly or disassembly of the component has to be allowed during the life of the product.

CAD

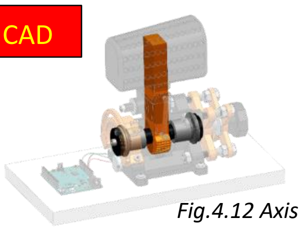


Fig.4.12 Axis system situation

PROTO

Fig.4.3 Throttle proto image

4.2.1 System S120 (AXIS) design explanation

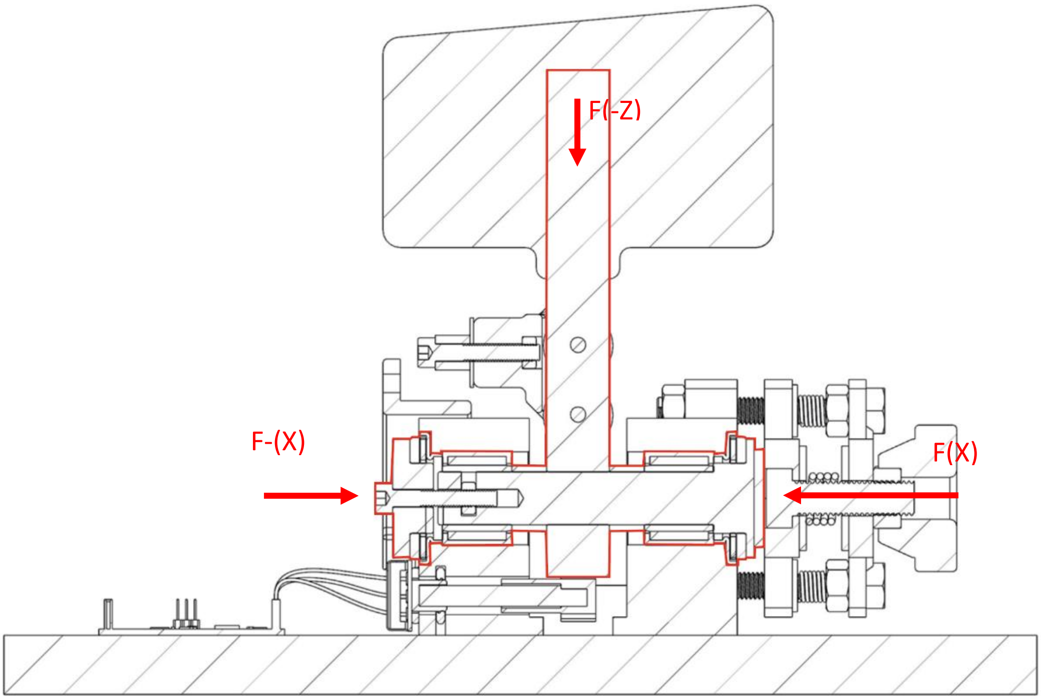


Fig.4.13 Throttle section view

The shaft (S120) is the system that allows the lever to perform a rotation movement smoothly consists of 16 components. For the shaft design (C1211), 2 pairs of roller bearings were chosen due to their small size. One pair of spokes (C126) allow rotation by supporting the radial force to the axis applied by the user of the lever (F-Z), another pair of axial (C124) to allow rotation when the brake (S130) this application axial force(FX) to shaft to cause friction between the shaft (C1210) and the brake (S120).

This composition of bearings is recommended by the manufacturer SKF for this type of combined loads.

The axis was produced in plastic, for a good fit with the rollers of the bearings, radial bearings NKI20 / 15 were chosen, that come with an inner interior for the shafts that cannot be rectified. In the case of axial bearings, the AXW 20 bearings, contain a rolling cage with the LS 2035 washer. They were used to avoid direct contact with plastic.

The diameter of the shaft is 25 mm, the system is next to a cover that is fixed with a screw to the shaft.

The lever (C128) is fixed in its center position from a bushing system (C127).

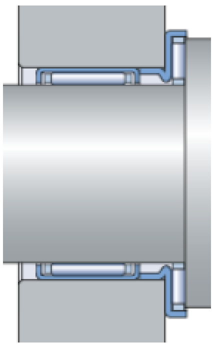


Fig.4.14 Skf recommended bearings layout for combined loads

4.2.2 Component C121 Top axis development sheet

REF	P/N	DESCRIPTION
1.2.1	C121	Top Axis

GEOMETRY OVERVIEW

SECTION Y=0

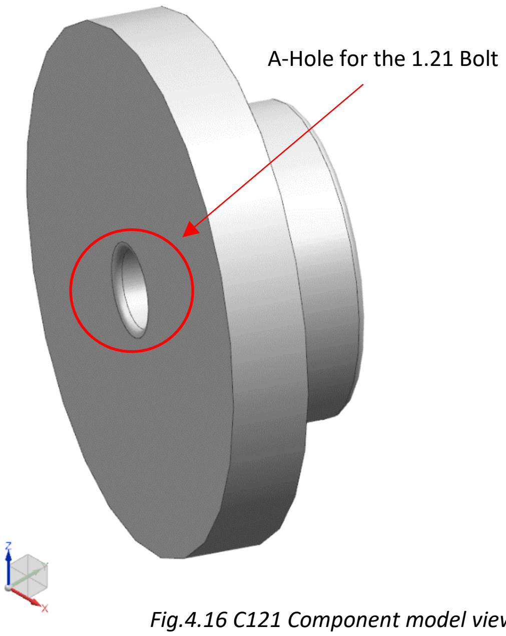
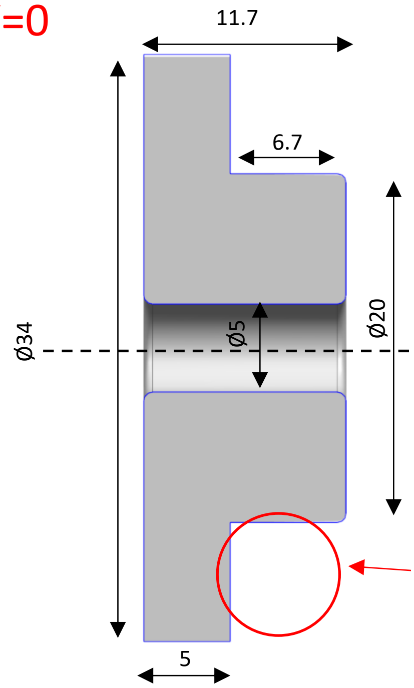


Fig.4.16 C121 Component model views



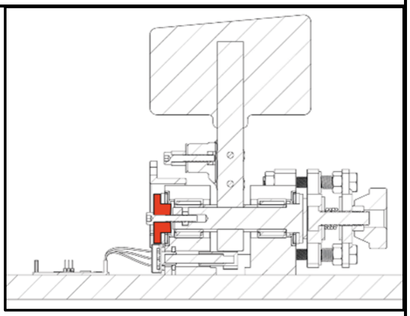


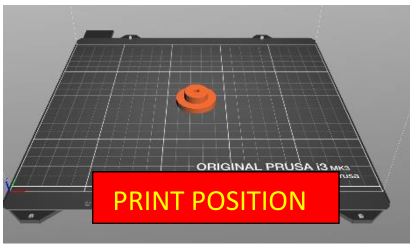
Fig.4.15 Component C121 situation

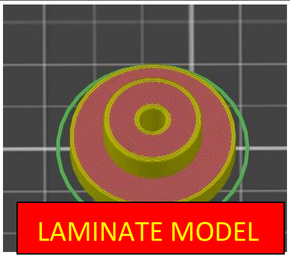
FUNCTIONALITY
Top to probide a close interface for the axis system.

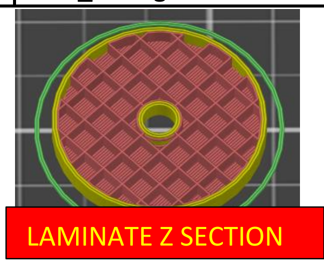
RELEVANT DESIGN ITEMS	
A	Hole for the C121 Bolt M5X30
B	Allocation for the C123 Washer axial bearing

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	TOP_AXIS..stl	TOP_AXIS.gcode

POS.		ROTATION
X	0	0
Y	0	90
Z	0	0







TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.17 C121 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.2.3 Component C124/5 axial bearing & Jail development sheet

BEARINGS SUMMARY			
REF	P/N	DESCRIPTION	MRKT REF.
1.2.4	C124	Axial Bearing	AXW20
1.2.5	C125	Jail Axis Bearing	

GEOMETRY OVERVIEW(SELECTED COMPONENT)

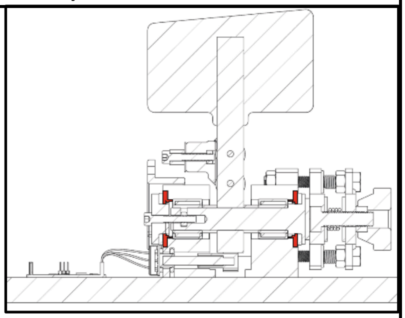
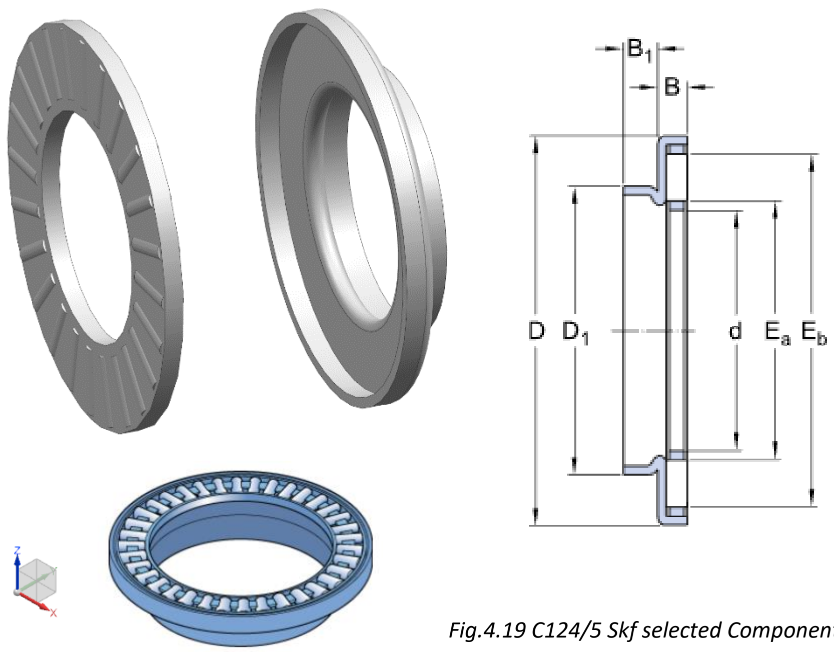


Fig.4.18 Component C124/5 situation



d		20
D		38
D_W		2
E_a	min.	22
E_b	max.	34
D_1		26
B		3.2
B_1		3.5

Fig.4.19 C124/5 Skf selected Component model views

PARAMETERS

Basic dynamic load rating	C	12	kN
Basic static load rating	C_0	47.5	kN
Fatigue load limit	P_u	5.6	kN
Reference speed		4300	r/min
Limiting speed		8500	r/min

Mass

Mass bearing with a centring flange		0.014	kg

FUNCTIONALITY

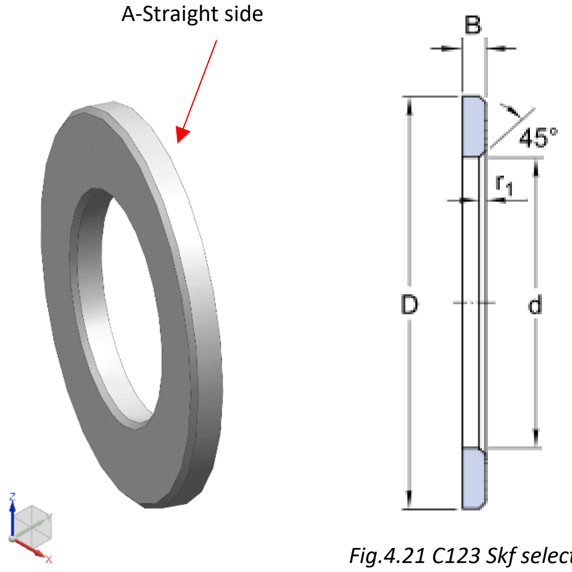
For provide smothness movement to the axis when a axial load is aplied.
Centring flange is needed due the meterial of the proto body is PETG , the bearing will not roll correctly through the plastic , there will not be smothness movement.

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	NG	Originally axis(Plastic) was in contact directly with the bearing , causing poor movement smothnes	Add washer LS 2035	OK

4.2.4 Component C123 Washer axial bearing development sheet

BEARINGS SUMMARY			
REF	P/N	DESCRIPTION	MRKT REF.
1.2.3	C123	Washer axial bearing	LS 2035

GEOMETRY OVERVIEW(SELECTED COMPONENT)



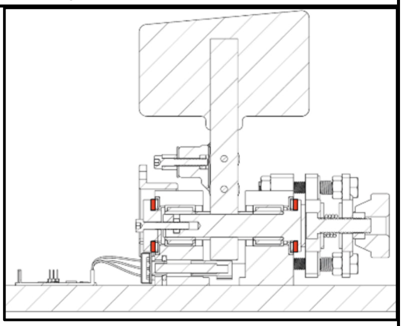


Fig.4.20 Component C123 situation

d		20	mm
D		35	mm
B		2.75	mm
r_1	min.	0.3	mm

Fig.4.21 C123 Skf selected Component model views

PARAMETERS

Mass		
Mass universal washer	0.013	kg

FUNCTIONALITY

For provide smothness movement to the axis when a axial load is aplied.
Washer axial bearing is needed due the material of the proto body is PETG, the bearing will not rolls correctly through the plastic , there will not be smothness movement.

RELEVANT DESIGN ITEMS

A	Stright side needs to be orientated to the rolling bearing (Manufacturer instructions)

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

4.2.5 Component C126 Radial bearing development sheet

BEARINGS SUMMARY

REF	P/N	DESCRIPTION	MRKT REF.
1.2.6	C126	Radial Bearing	NKI15/20

GEOMETRY OVERVIEW (SELECTED COMPONENT)

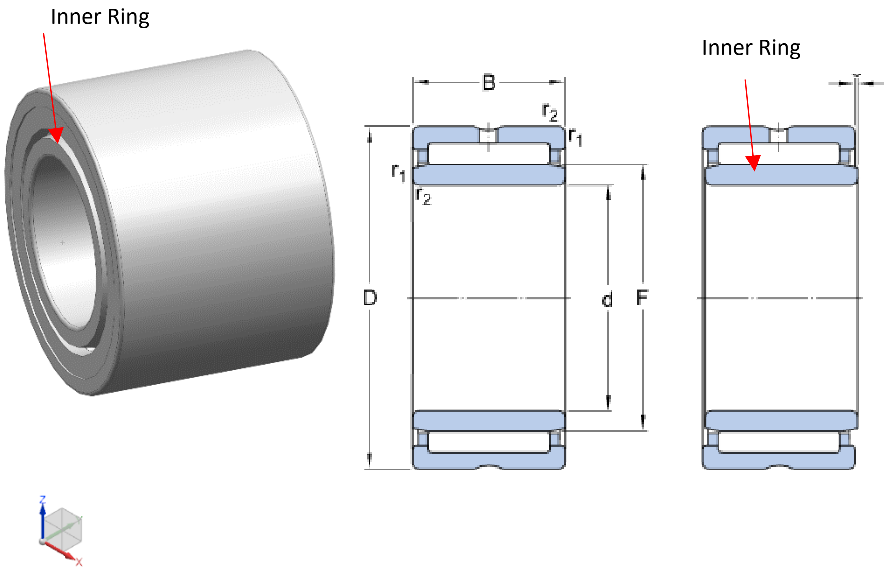


Fig.4.23 C126 Skf selected Component model views

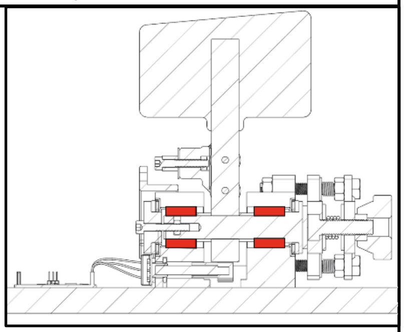


Fig.4.22 Component C126 situation

d		15
D		27
B		20
F		19
$r_{1,2}$	min.	0.3
s	max.	0.5

PARAMETERS

Basic dynamic load rating	C	16.5
Basic static load rating	C_0	25.5
Fatigue load limit	P_u	3.05
Reference speed		20000
Limiting speed		24000

Mass

Mass bearing with a centring flange	0.049

FUNCTIONALITY

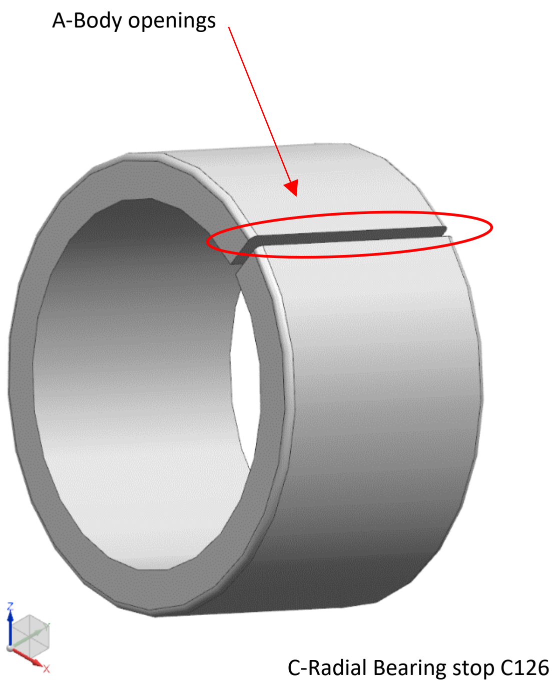
For provide smothness movement to the axis when a radial load is aplied.
Needle roller bearings with machined inner and outer rings is needed due the meterial of the proto body is PETG , the bearing will not rolls correctly through the plastic , there will not be smothness movement.

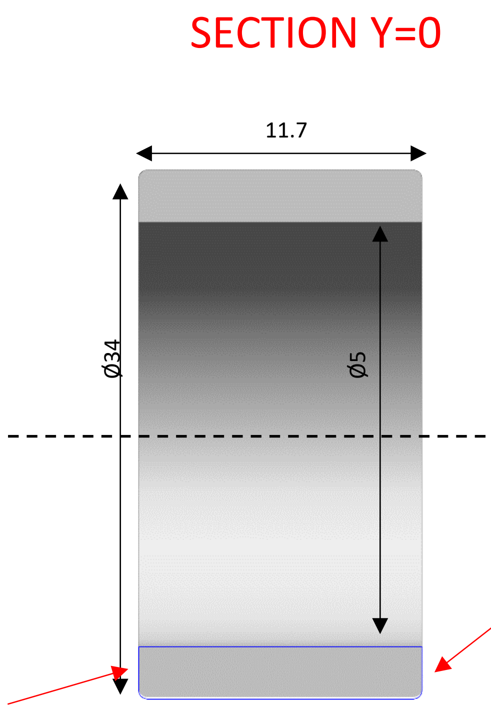
TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

4.2.6 Component C127 Cap axis development sheet

REF	P/N	DESCRIPTION
1.2.7	C127	Cap Axis

GEOMETRY OVERVIEW





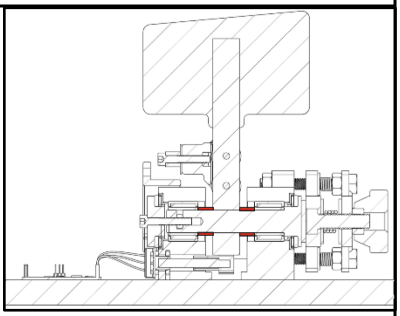


Fig.4.24 Component C127 situation

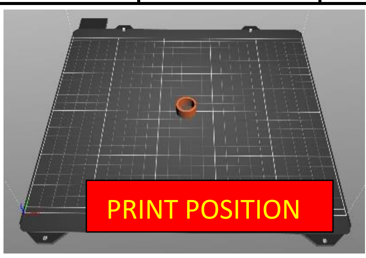
Fig.4.25 C127 Component model views

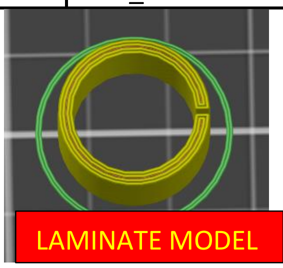
FUNCTIONALITY
Cap to provide fixation to the lever, and radial bearings. Fix the lever to the center position and doesn't allow the dislacemetn on x direction.

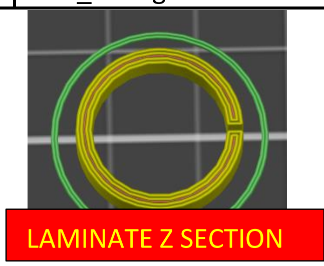
RELEVANT DESIGN ITEMS	
A	Body openings to ensure axis fixation due 3d print tolerances (clamp functionality)
B	Lever stop
C	Radial bearing stop

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	CAP_AXIS.stl	CAP_AXIS.gcode

POS.		ROTATION
X	0	0
Y	0	90
Z	0	0







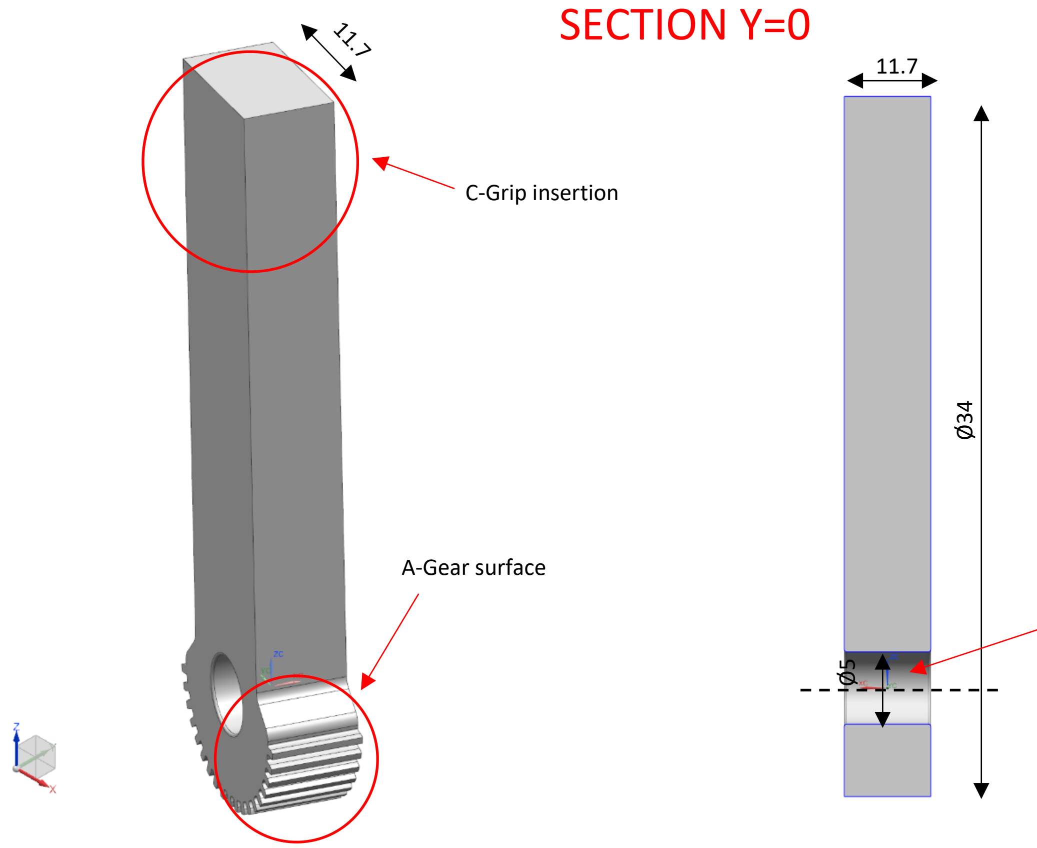
TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.26 C127 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.2.7 Component C128 Lever development sheet

REF	P/N	DESCRIPTION
1.2.8	C128	Lever

GEOMETRY OVERVIEW



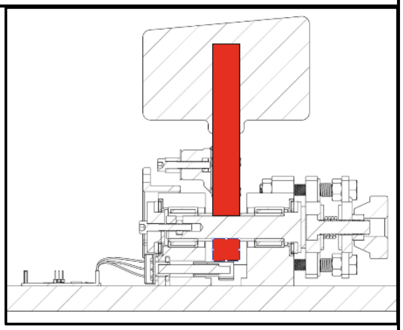


Fig.4.27 Component C128 situation

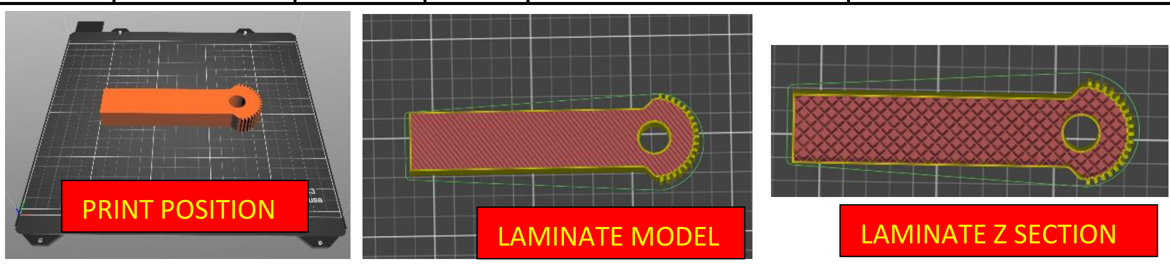
Fig.4.28 C128 Component model views

FUNCTIONALITY
User interface to rotate and adjust depending the position amount engine power

RELEVANT DESIGN ITEMS	
A	Lever ends with a gear surface to transmit their position to the potentiometer
B	Axis hole
C	Grip Insertion

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR:Orange
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	Lever.stl	Lever.gcode

POS.		ROTATION
X	0	0
Y	0	90
Z	0	0



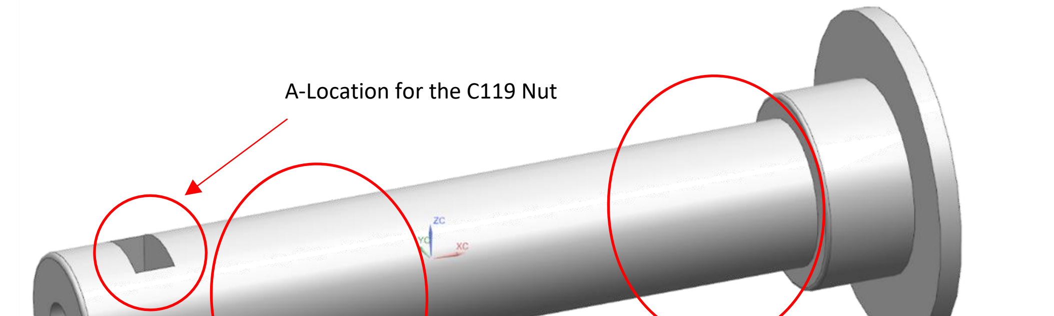
TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.30 C128 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.2.8 Component C1210 Axis development sheet

REF	P/N	DESCRIPTION
1.2.10	C1210	Axis

GEOMETRY OVERVIEW



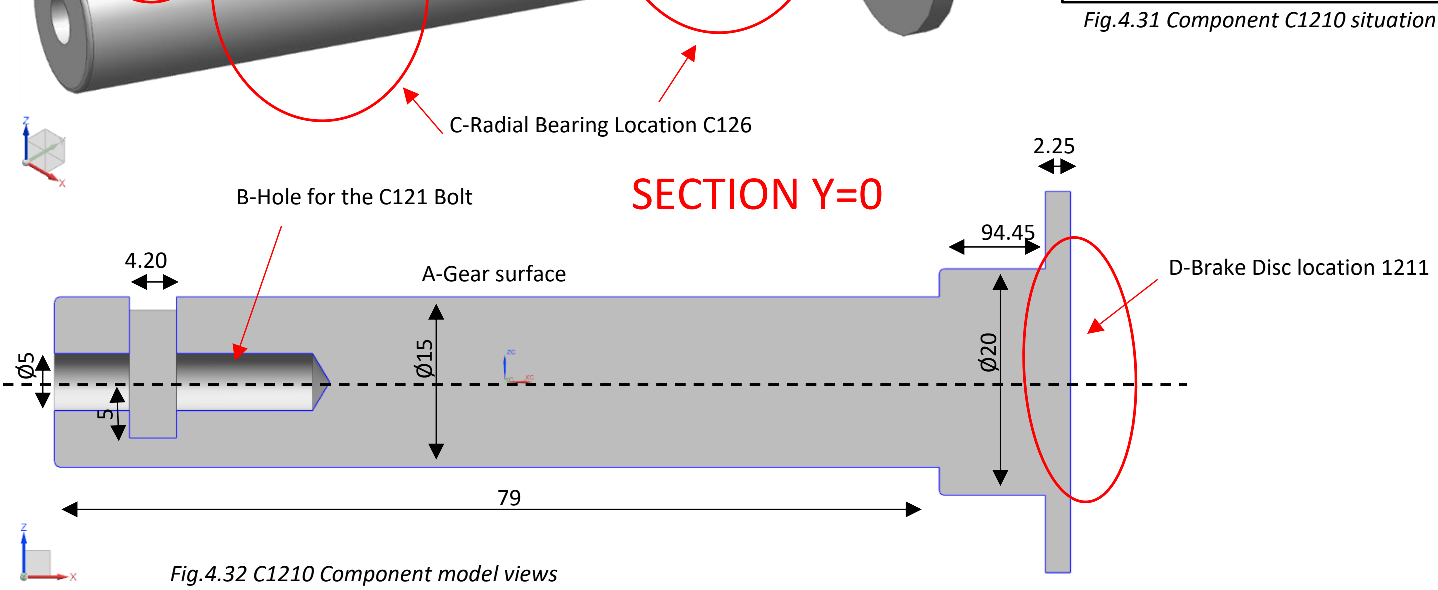


Fig.4.32 C1210 Component model views

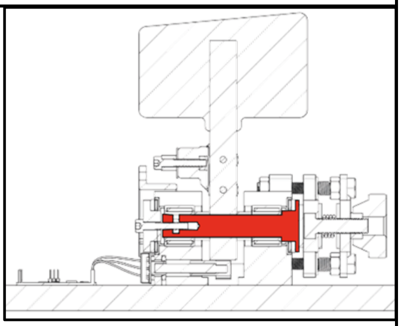


Fig.4.31 Component C1210 situation

FUNCTIONALITY

Element of the mechanics used to guide the rotation movement of a lever through the bearings.

RELEVANT DESIGN ITEMS

A	Lever ends with a gear surface to transmit their position to the potentiometer
B	Hole for the C121 Bolt
C	Radial Bearing Location C126
D	Brake Disc location 1211

SPECIFIC COMPONENT DESIGN REQUIREMENT

DURABILITY	By durability point of view, this component has the worst condition, is subjected a lot of stress by loads provided by the others systems.

LOADS OVERVIEW

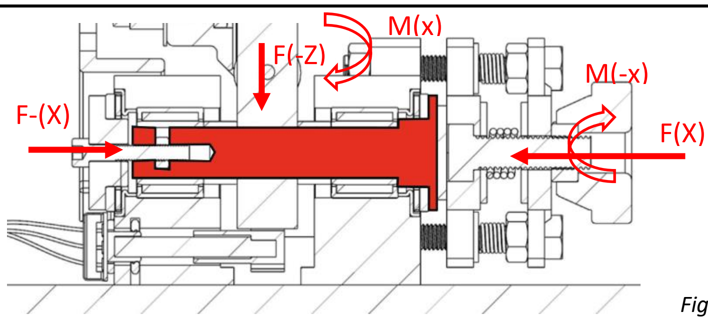
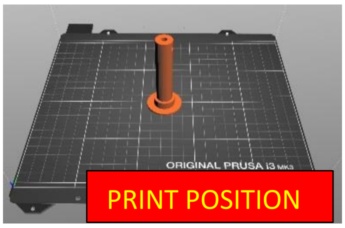


Fig.4.33 Axis loads diagram

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	50%	NO	AXIS.stl	AXIS.gcode

POS.		ROTATION
X	0	0
Y	0	-90
Z	0	0



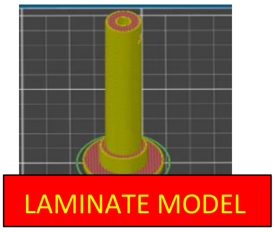


Fig.4.8 C111 Component Prusa 3D printer model views (position, laminate model, laminate section)

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	NG	Originally the print filling was the standard 20%, During assembly and test the proto axis fail and broked , consecaunce of the loads during test procees	Increase filling from 20% to 50%	OK

Original filling structure (20%)	C/M filling structure (50%)

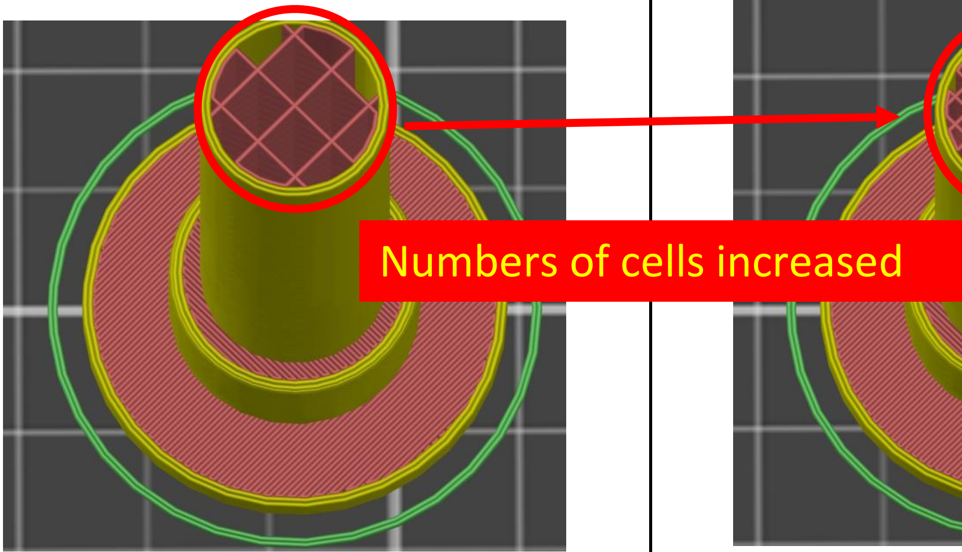


Fig.4.34 Axis legacy filling structure image

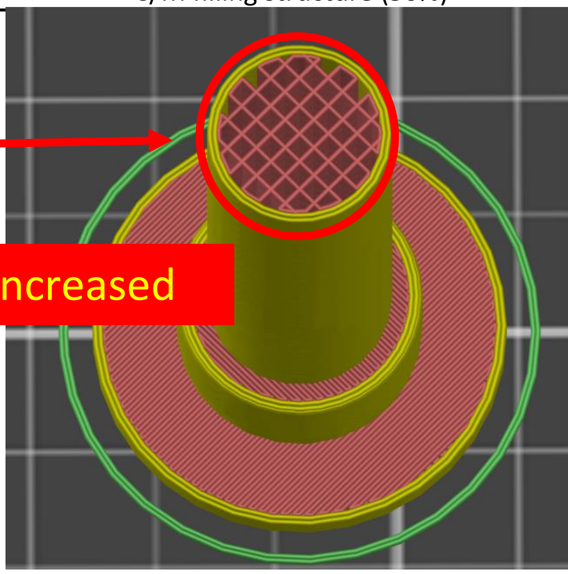


Fig.4.35 C/M filling structure image

TEST RESULTS	TEST RESULTS C/M

Fig.4.36 Axis legacy test result (fail)

Fig.4.37 Axis with C/M test result (OK)

4.2.9 Component C1211 Brake disc development sheet

REF	P/N	DESCRIPTION
1.2.11	C1211	Brake disc

GEOMETRY OVERVIEW (SELECTED COMPONENT)

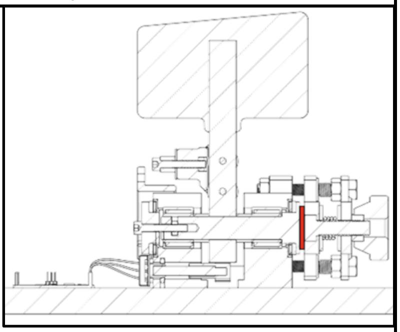


Fig.4.38 Component C1211 situation

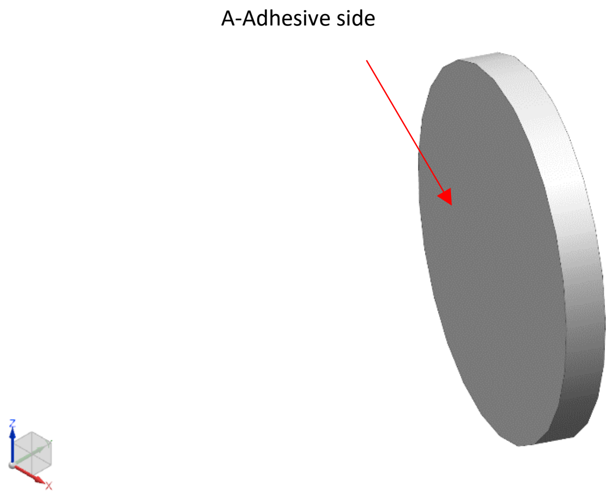


Fig.4.39 C1211 Component model views

FUNCTIONALITY

To have a better fricttion throught the axis and the frriction regulation mecanism , the disk is made by fibers , has better friction feeling instead (plastic/plastic).

RELEVANT DESIGN ITEMS

A	One side has adessive and its placed on the right end of the axis

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

4.3 System S130 Friction regulation development sheet

SYS 1.3 Friction regulation

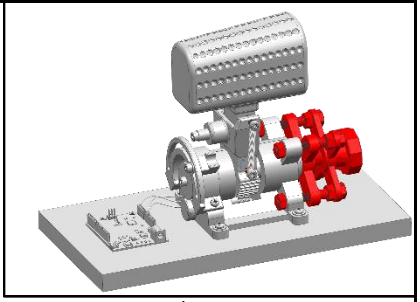


Fig.4.40 Friction regulation system situation

-

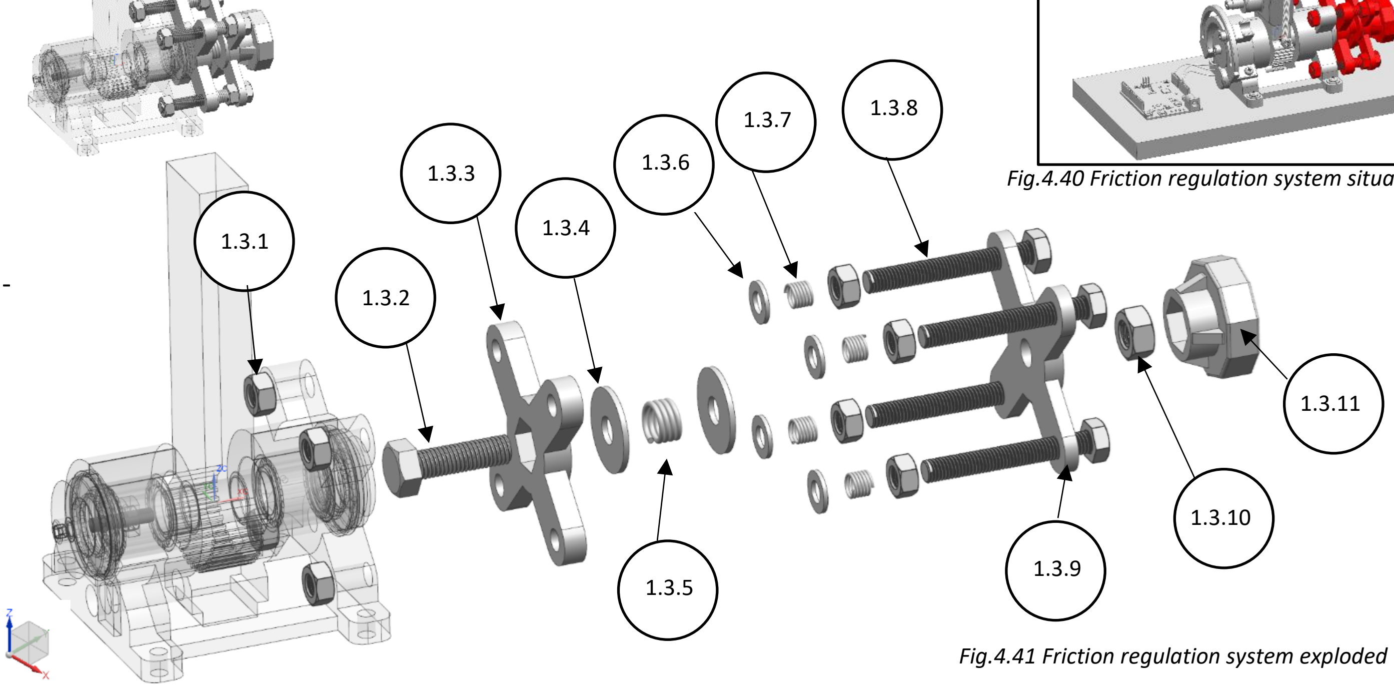


Fig.4.41 Friction regulation system exploded view

		Component description		P/N	General dimensions	Material	Mass	CAD DATA
1.3	F. regulation			S130				S_F_REGULATION.prt
		1.3.1	X8 Nut M8	C131	M8X6.5	Steel		NUT_M8.prt
		1.3.2	X8 Bolt M10X35	C132	M10X35	Steel		BOLT_M10X35.prt
		1.3.3	Brake	C133	10X89.35X89.35	PET G		BRAKE.prt
		1.3.4	Washer M10	C134	Ø10X Ø30X2	Steel		WASHER_M10.prt
		1.3.5	Spring M10	C135	Ø13.5X21	Steel		SPRING_M10.prt
		1.3.6	Washer M5 medium	C136	Ø5X Ø15X1.5	Steel		WASHER_M5_M.prt
		1.3.7	Spring M8	C137	Ø8X25	Steel		SPRING_M8.prt
		1.3.8	Bolt M8X60	C138	M8X60	Steel		BOLT_M8X60.prt
		1.3.9	Brake bedplate	C139	7X68.67X68.67	PET G		BRAKE_BEDPLATE.prt
		1.3.10	Nut M10	C1310	M10X8	Steel		NUT_M10.prt
		1.2.11	Brake Wheel	C1211	22.5X40X40	PET G		BRAKE_WHEEL.prt

FUNCTIONALITY

Adjust friction against the axis, so the user can adjust to his preferences the amount of force needed to move the lever

TARGET PERFORMANCE

Smooth friction, adjustable with one hand, easy to operate

DESIGN REQUIREMENTS

DURABILITY

By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality

FESEABILITY

Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.

WORKABILITY AND SERVICEABILITY

The assembly or disassembly of the component has to be allowed during the life of the product.

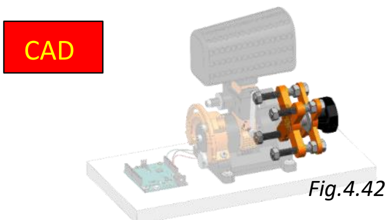


Fig.4.42 Friction regulation system situation

Fig.4.3 Throttle proto image

4.3.1 System S130 (FRICTION REGULATION) design explanation

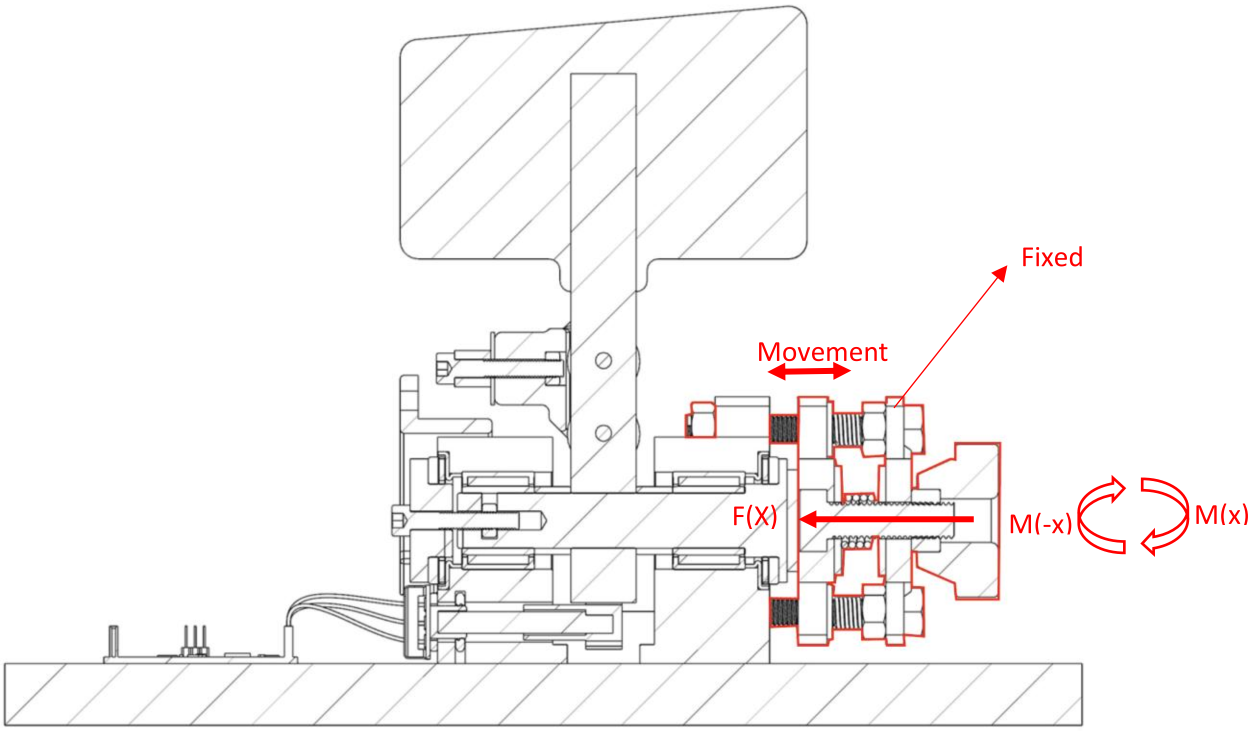


Fig.4.13 Throttle section view

The FRICTION REGULATION System (S130) is responsible for generating a frictional force against the rotary movement of the shaft. The system can regulate the amount of normal force applied against the shaft, regulating the friction and the amount of force necessary for the user to operate the lever.

The system has a plate (C133) that can be moved on a guide of 4 screws (C138), this same plate (C133) is what serves as a brake pressing the shaft (S120) and causing friction between the two elements.

The plate is moved by a screw (C132) fixing the screw head to the plate (C133), the screw incorporates a spring (C135), at the end of this is another fixed plate (C139) with the nut (C1310) and the handle (C1311).

When turning the handle in a clockwise direction, the screw is tightening (C132) with the plate and the spring (C135) is compressed, relaxing the pressure against the shaft and generating less friction.

Turning the handle counterclockwise expands the spring exerting more pressure against the shaft.

The 4 screws (C138) that work as guides also regulate the maximum frictional force caused by the central spring (C135), the springs in the guides (C137) help the movement of the plate (C133) to be uniform.

The component (C139) is fixed and acts as a bench for the springs (C135/7) and the nut (C1310).

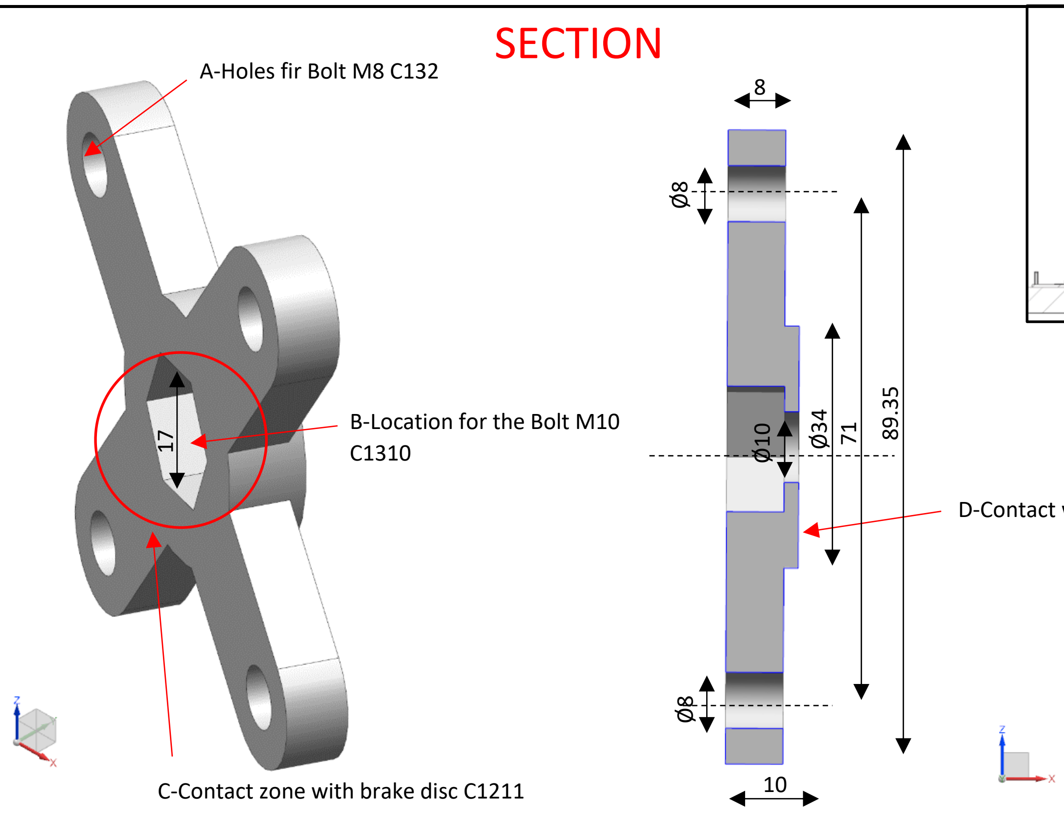
To distribute the force of the springs between the plastic, washing machines are used (C134/ 6).

In the end of the shaft (12010) there is a disc (C12011) made by fibrous material that facilitates a coefficient of friction with a pleasant sensation.

4.3.2 Component C133 Brake development sheet

REF	P/N	DESCRIPTION
1.3.3	C133	Brake

GEOMETRY OVERVIEW



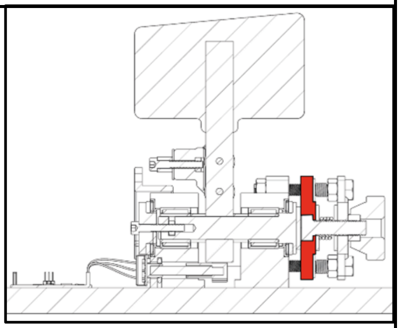


Fig.4.43 Component C133 situation

Fig.4.44 C133 Component model views

FUNCTIONALITY

Apply friction to the axis

RELEVANT DESIGN ITEMS

A	Lever ends with a gear surface to transmit their position to the potentiometer
B	Hole for the C121 Bolt
C	Radial Bearing Location C126
D	Brake Disc location 1211

SPECIFIC COMPONENT DESIGN REQUIREMENT

DURABILITY	By durability point of view, this component has the worst condition, is subjected a lot of stress by loads provided by the others systems.

LOADS OVERVIEW

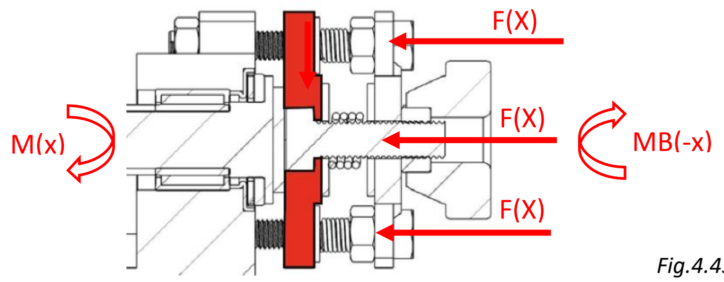
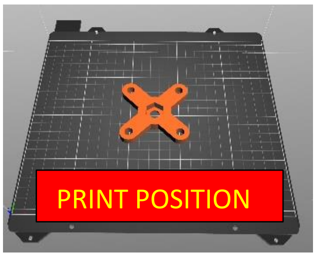
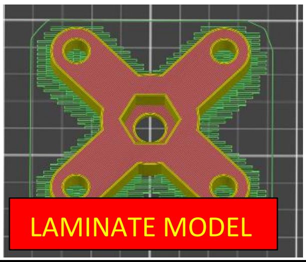


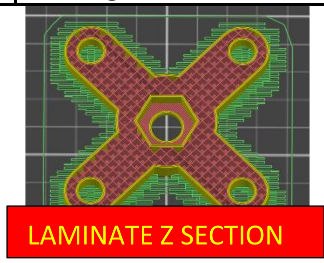
Fig.4.45 Brake loads diagram

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: orange
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	30%	YES	Brake.stl	Brake.gcode

POS.		ROTATION
X	0	0
Y	0	-90
Z	0	0







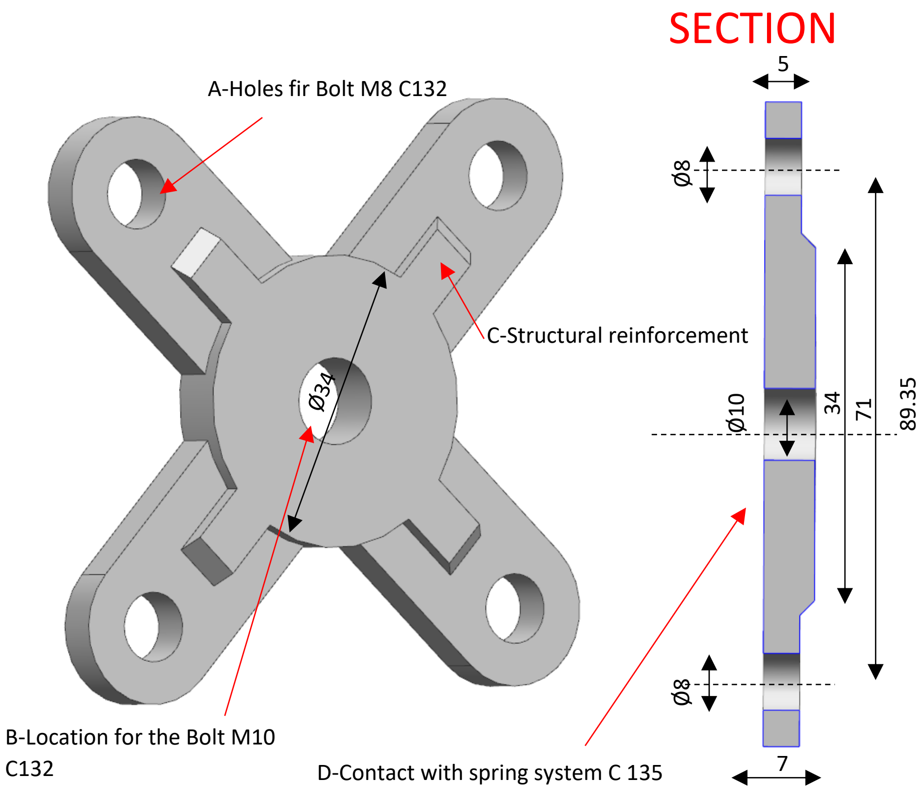
TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.46 C133 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.3.3 Component C134 Brake bedplate development sheet

REF	P/N	DESCRIPTION
1.3.4	C134	Brake bedplate

GEOMETRY OVERVIEW



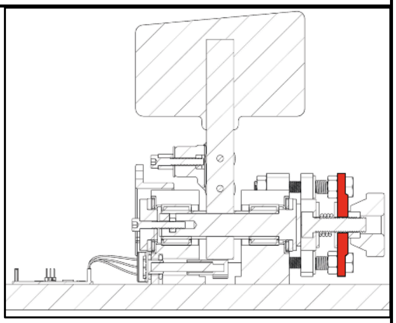


Fig.4.47 Component C134 situation

Fig.4.48 C134 Component model views

FUNCTIONALITY
Fixed bedplate to allow the springs press the brake

RELEVANT DESIGN ITEMS	
A	Lever ends with a gear surface to transmit their position to the potentiometer
B	Hole for the C132 Bolt
C	Structural reinforcement
D	Brake Disc location 1211

SPECIFIC COMPONENT DESIGN REQUIREMENT	
DURABILITY	By durability point of view, this component has the worst condition, is subjected a lot of stress by loads provided by the others systems.

LOADS OVERVIEW

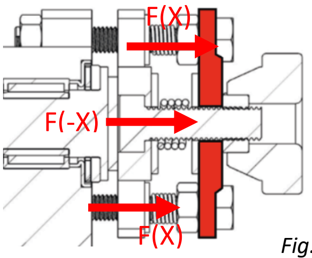
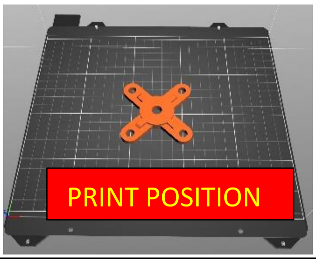
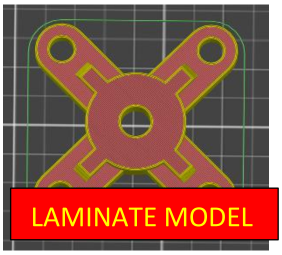
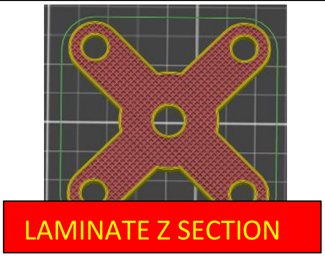


Fig.4.49 Brake bedplate loads diagram

<table>
<tr><td colspan="7">PROTO MANUFACTURE PARAMETERS</td><td>MATERIAL COLOR: orange</td></tr>
<tr><td colspan="2">3D printer model</td><td>MATERIAL</td><td>QUALITY</td><td>FILLING</td><td>BASES</td><td>STL DATA</td><td>GCODE DATA</td></tr>
<tr><td colspan="2">PRUSA MK3</td><td>PET G</td><td>0.15mm</td><td>50%</td><td>NO</td><td>Brake_bedplate.stl</td><td>Brake_bedplate.gcode</td></tr>
<tr><td>POS.</td><td>ROTATION</td><td colspan="6" rowspan="4">




</td></tr>
<tr><td>X 0</td><td>0</td></tr>
<tr><td>Y 0</td><td>90</td></tr>
<tr><td>Z 0</td><td>0</td></tr>
</table>

TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

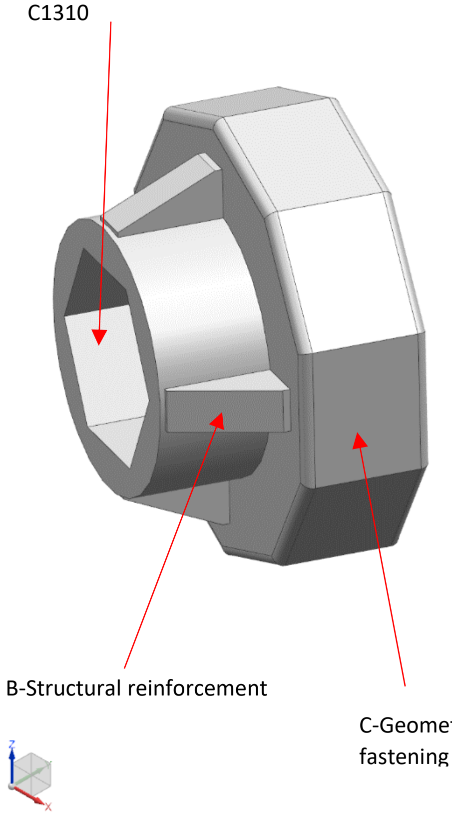
Fig.4.50 C134 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.3.4 Component C1311 Brake wheel development sheet

REF	P/N	DESCRIPTION
1.3.11	C1311	Brake Wheel

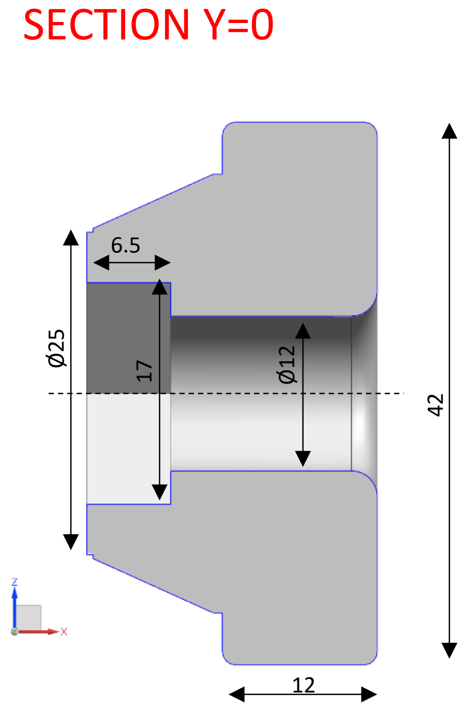
GEOMETRY OVERVIEW

A-Location for the Nut M10 C1310



B-Structural reinforcement

C-Geometry for better user fastening



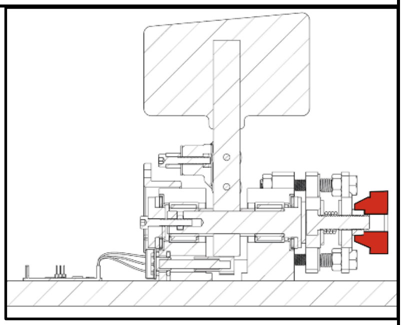


Fig.4.51 Component C1311 situation

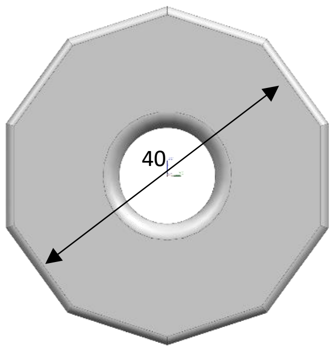


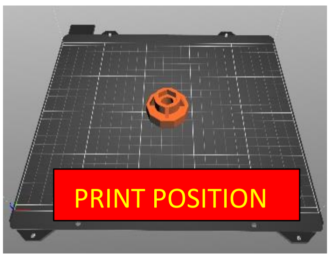
Fig.4.6 C1311 Component model views

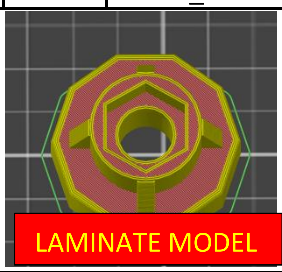
FUNCTIONALITY
Rotating the wheel , user can adjust the level of frriction (the bolt is thighten or unthighten)

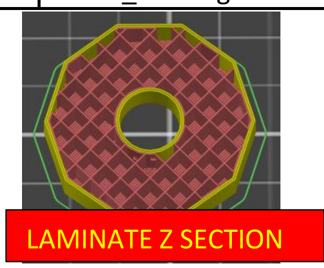
RELEVANT DESIGN ITEMS	
A	Location for the Nut M10 C1310
B	Structural reinforcement
C	Geometry for better user fastening

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	Brake_wheel.stl	Brake_wheel.gcode

POS.		ROTATION
X	0	0
Y	0	-90
Z	0	0







TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.52 C1311 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.4 System S130 Flight detents development sheet

SYS 1.4 Flight detens

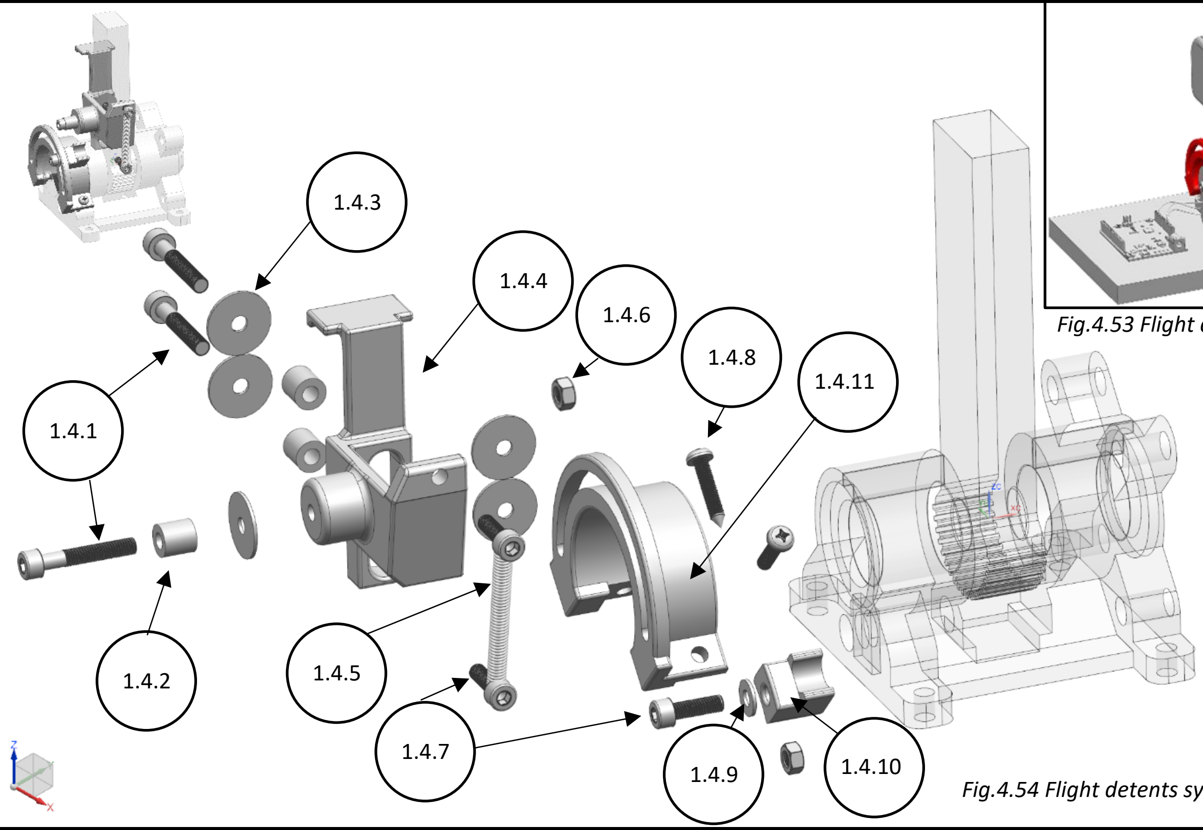


Fig.4.54 Flight detents system exploded view

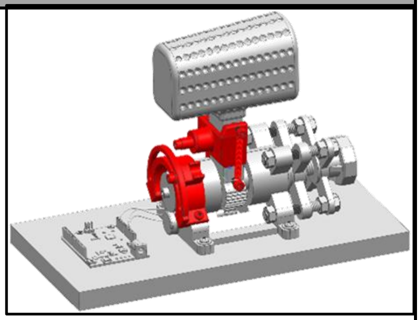


Fig.4.53 Flight detents system situation

		Component description		P/N	General dimensions	Material	Mass	CAD DATA
1.4	Flight detents			S130				S_FLIGHT_DETENTS.prt
		1.4.1	X3 Bolt M5X30	C141	M5X30	Steel		BOLT_M5X30.prt
		1.4.2	X3 Cap M5	C142	Ø10X Ø15X10	Steel		CAP_M5.prt
		1.4.3	X5 Washer M5	C143	Ø20X Ø5X1	Steel		WASHER_M5.prt
		1.4.4	FD lever	C144	40X48X80	PET G		FD_LEVER.prt
		1.4.5	Spring Tension	C145	Ø2.5X42.9	Steel		SPRING_TENSION.prt
		1.4.6	X2 Nut M5	C146	M5X4	Steel		NUT_M5.prt
		1.4.7	X3 Bolt M5X15	C147	M5X15	Steel		BOLT_M5X15.prt
		1.4.8	X2 Screw M5x20	C148	M5x20	Steel		SCREW_M5X20.prt
		1.4.9	Washer M5 small	C149	Ø10X Ø5X1	Steel		WASHER_M5_SMALL.prt
		1.4.10	FD Cut off	C1410	15X16x16.8	PET G		FD_CUT_OFF.prt
		1.4.11	FD Support guide	C1411	82X80X25.3	PET G		FD_SUPPORT_GUIDE.prt

FUNCTIONALITY
Provide, movement stops on determines zones of the displacement, for example for idle position or cut off
TARGET PERFORMANCE
Easy to operate , provide solid detents , marked positions
DESIGN REQUIREMENTS
DURABILITY
By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality
FESEABILITY
Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.
WORKABILITY AND SERVICEABILITY
The assembly or disassembly of the component has to be allowed during the life of the product.

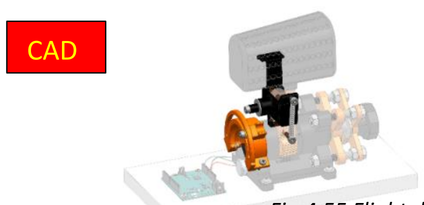


Fig.4.55 Flight detents system situation

Fig.4.3 Throttle proto image

4.4.1 System S130 (FLIGHT DETENTS) design explanation

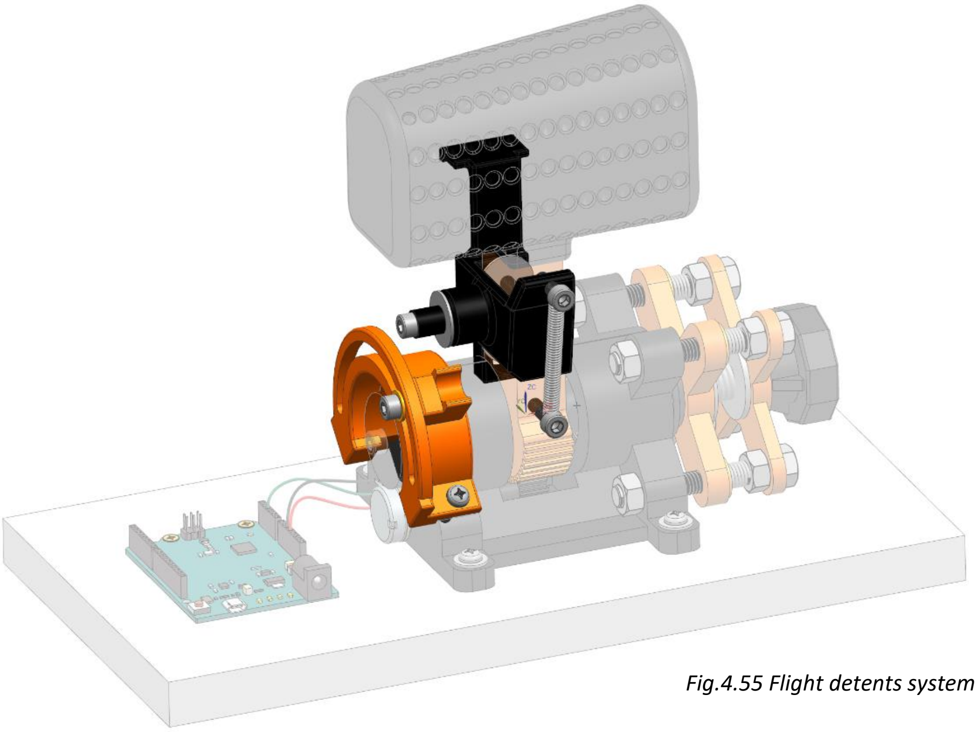


Fig.4.55 Flight detents system situation

Flight detent system provide stop on the lever travel for the engine cut off.

This flight detent position can be move to every position on the lever travel thanks a guide on the component (C1411). When the throttle is moved to the lower position the bolt (C141) impacts to the cut off flight detent (C1410) that position is idle detent. To exit from idle and enter in the cut off position it's necessary to upper the flight detent lever and rotate the throttle to the cut off.

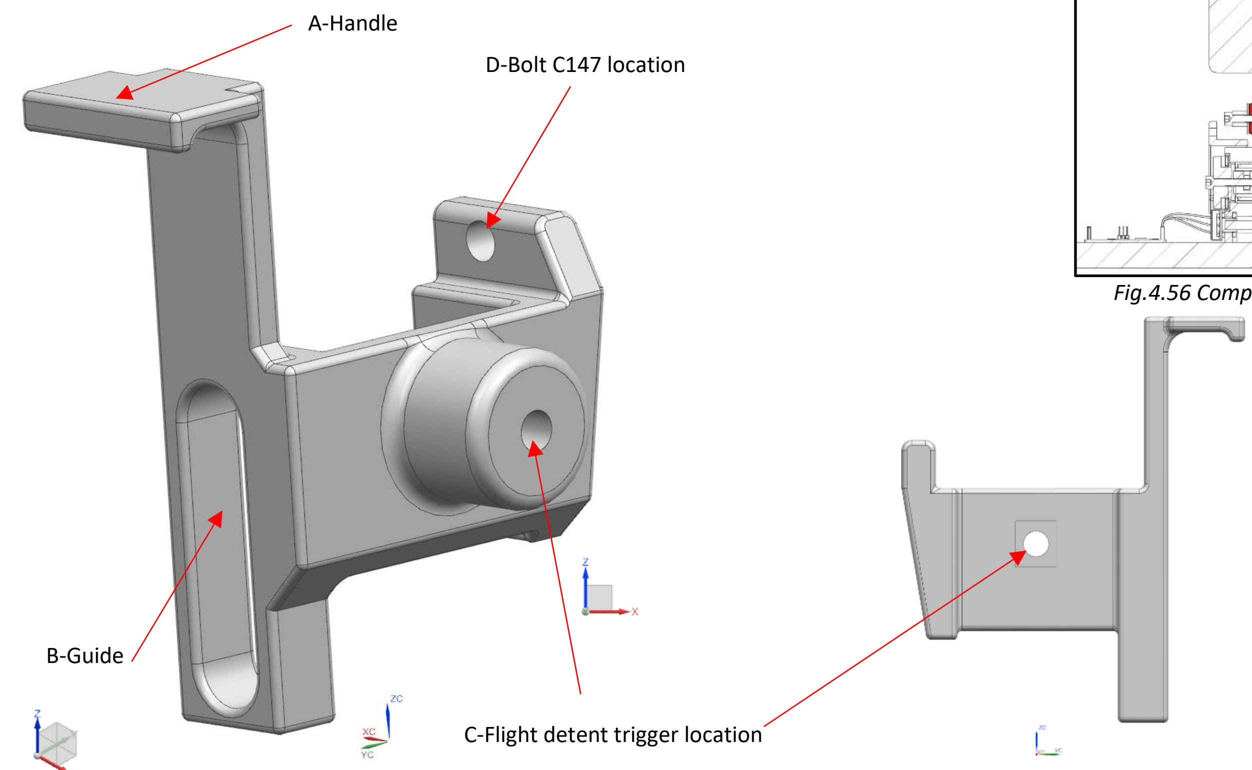
User can enter to the cut off position elevating the FD lever (C144) to the upper position, moving the throttle to the lower position and then fitting the bolt (C141) inside the cut off flight detent (C1410).

Flight detent Lever can move because of a guide consisting on a large hole (C1411) and 2 bolts (C141) with a little cylinder inside (C142) that rotates when an upper force is applied. If no force is applied the spring return the lever to the lower position, not allowing the cut of position.

4.4.2 Component C144 FD lever development sheet

REF	P/N	DESCRIPTION
1.4.4	C144	FD lever

GEOMETRY OVERVIEW



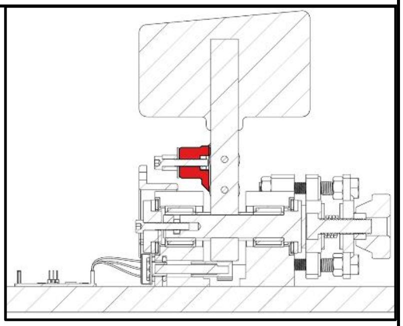


Fig.4.56 Component C144 situation

Fig.4.6 C144 Component model views

FUNCTIONALITY

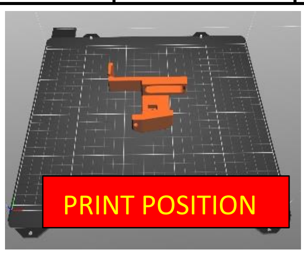
Lever can be moved up and down with a selfguide , this diplacement generate the enter or exit in a flight detent

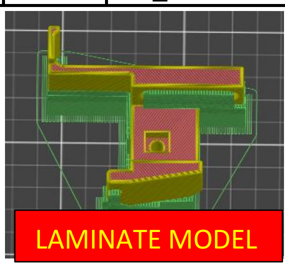
RELEVANT DESIGN ITEMS

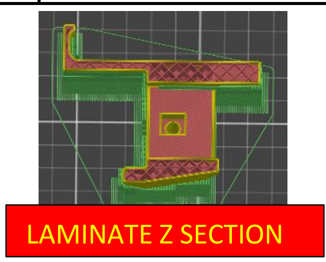
A	Handle for user
B	Guide for the movement of the flight detent lever , allows 10 mm movement on Z aixs
C	Flight detent trigger location with interior nut C146
D	Bolt C147 location for returning spring

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	YES	FD_LEVER.stl	FD_LEVER.gcode

POS.		ROTATION
X	0	0
Y	0	90
Z	0	0







TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.57 C144 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.4.3 Component C1410 FD Cut off development sheet

REF	P/N	DESCRIPTION
1.4.10	C1410	FD cut off

GEOMETRY OVERVIEW

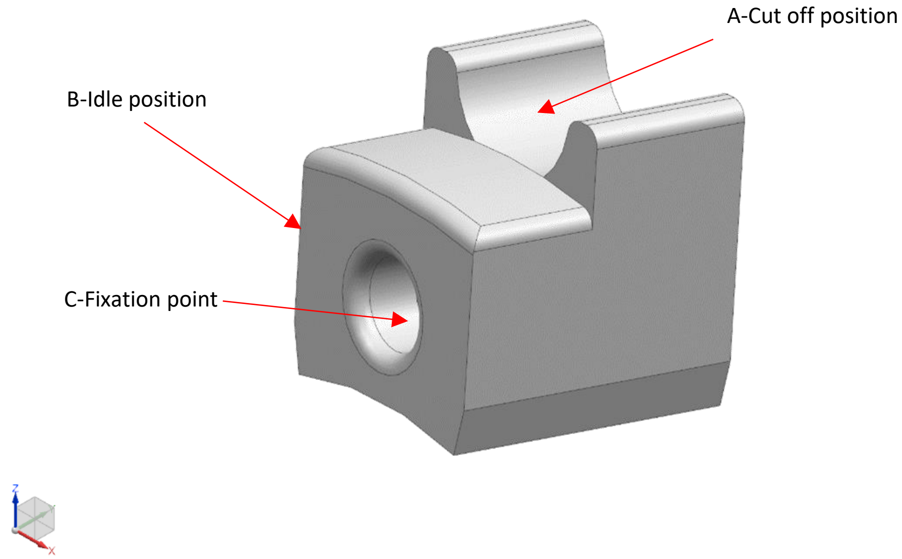


Fig.4.59 C1410 Component model views

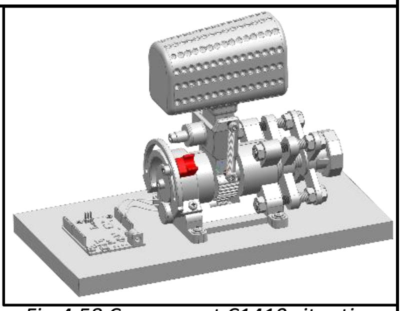


Fig.4.58 Component C1410 situation

FUNCTIONALITY

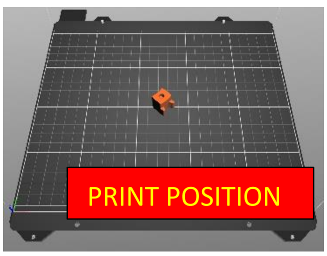
Provide stops for idle detent and cut off position.

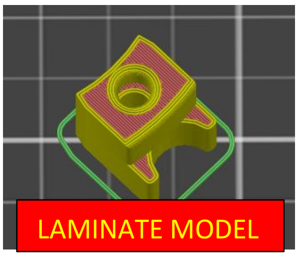
RELEVANT DESIGN ITEMS

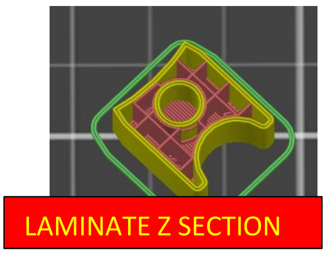
A	Location for the Bolt C141 (cut off position)
B	Idle position
C	Fixation for position regulation

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: orange
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	FD_cut_offr.stl	FD_cutt_off.gcode

POS.		ROTATION
X	0	0
Y	0	-90
Z	0	0







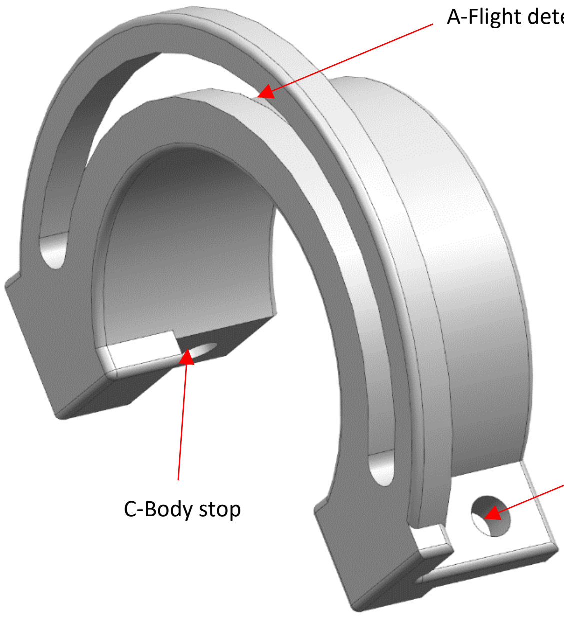
TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

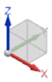
Fig.4.60 C1410 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.4.4 Component C1410 FD support guide development sheet

REF	P/N	DESCRIPTION
1.4.11	C1411	FD support guide

GEOMETRY OVERVIEW





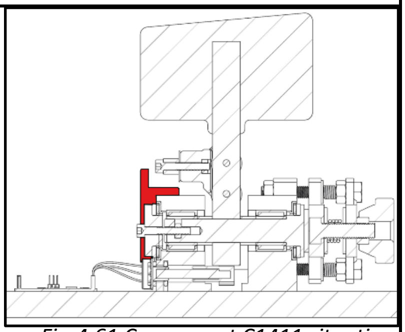


Fig.4.61 Component C1411 situation

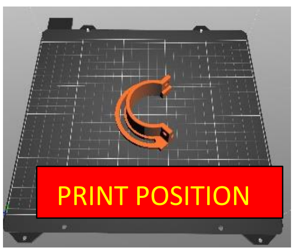
Fig.4.62 C1411 Component model views

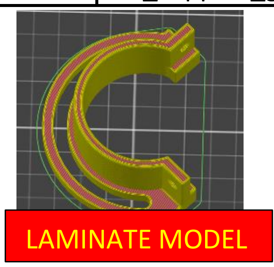
FUNCTIONALITY
Support guide to place the flight detent at eny position between 180Deg.

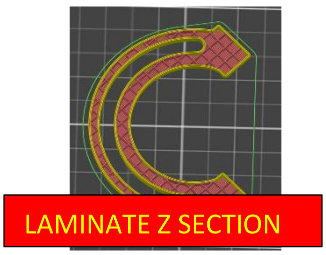
RELEVANT DESIGN ITEMS	
A	Flight detents guide
B	Fixation point
C	Body stop

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: orange
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	FD_support_guide.stl	Fd_support_guide.gcode

POS.		ROTATION
X	0	0
Y	0	90
Z	0	0





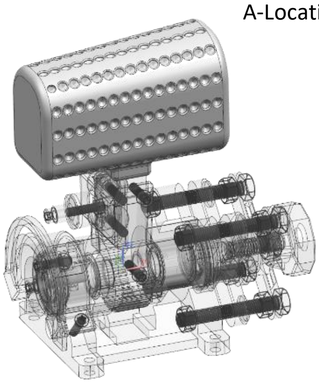


TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	OK	-	N/A	N/A

Fig.4.63 C1411 Component Prusa 3D printer model views (position, laminate model, laminate section)

4.5 System S150 Grip development sheet

SYS 1.5 Grip



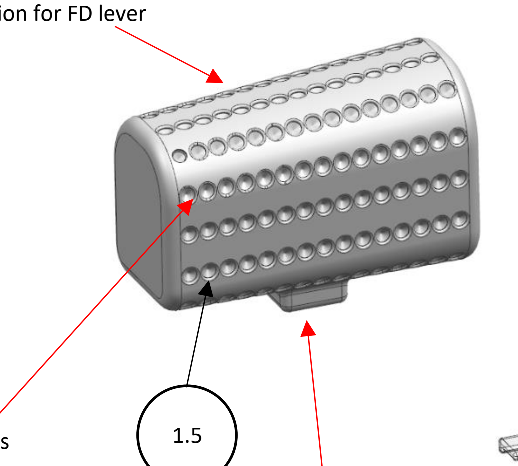


Fig.4.65 Grip system exploded view

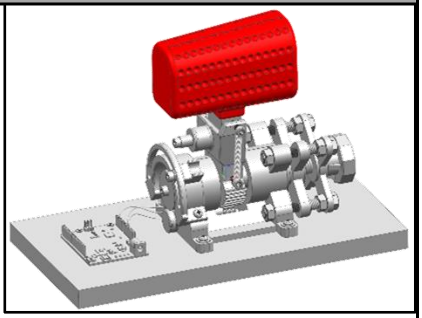
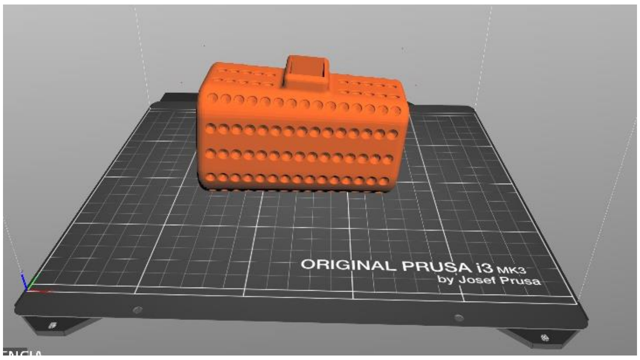


Fig.4.64 Grip system situation

MATERIAL	QUALITY	FILLING	BASES
PET G	0.15mm	20%	NO



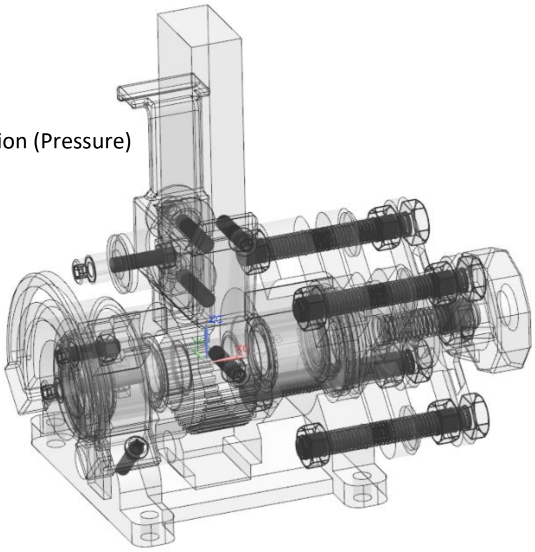


Fig.4.66 C150 Component Prusa 3D printer model views (position)

		Component description	P/N	General dimensions	Material	Mass	CAD DATA
1.5	Grip		S150	112X55X70	PETG		S_GRIP.prt

FUNCTIONALITY
User interface with the throttle
TARGET PERFORMANCE
Request adapt to the hand , ergonomic , anti-skid
DESIGN REQUIREMENTS
DURABILITY
By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality
FESEABILITY
Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.
WORKABILITY AND SERVICEABILITY
The assembly or disassembly of the component has to be allowed during the life of the product.

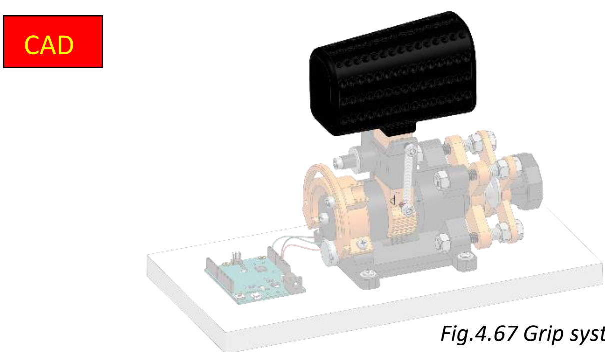


Fig.4.67 Grip system situation

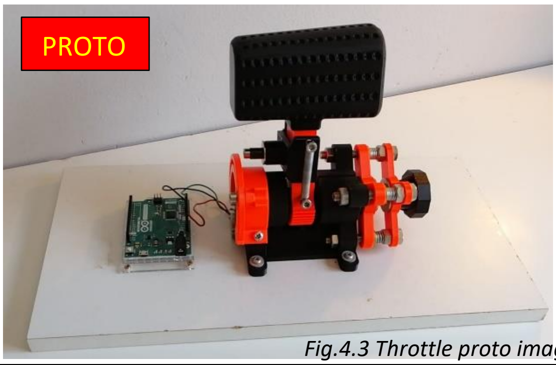


Fig.4.3 Throttle proto image

4.6 System S160 Position control development sheet

SYS 1.6 Position control

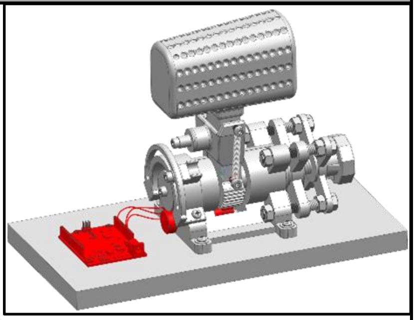


Fig.4.68 Position control system situation

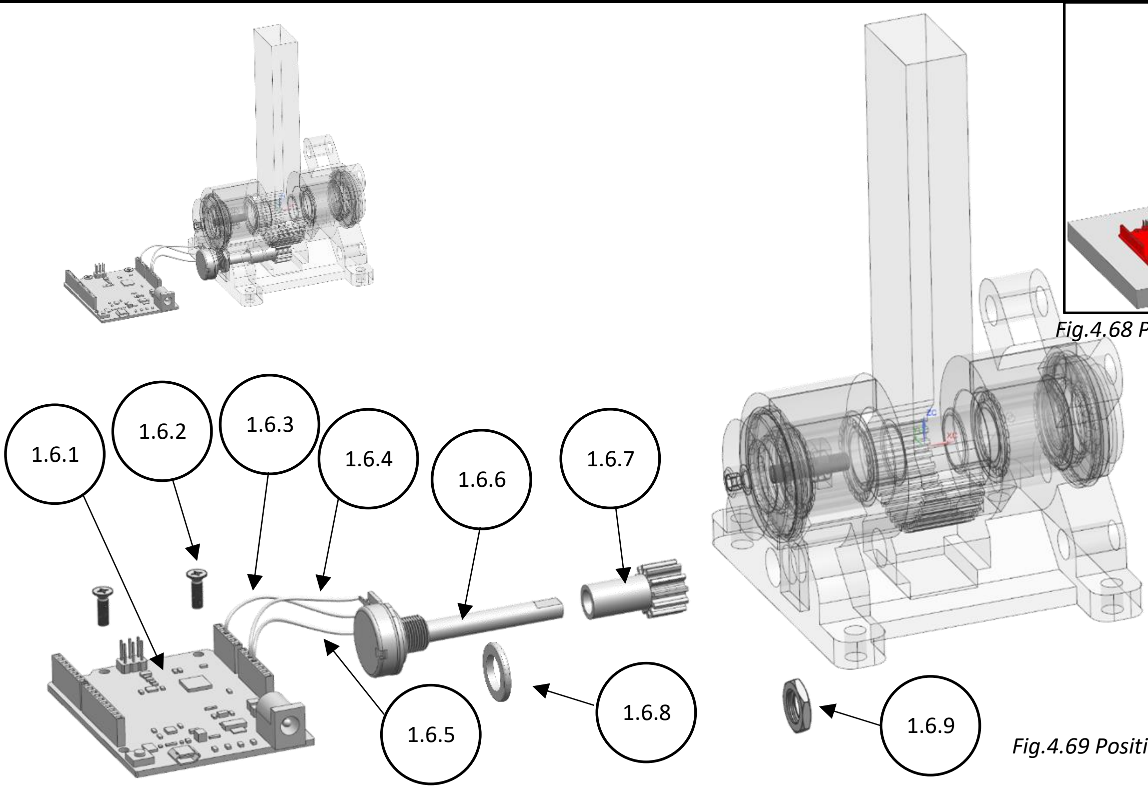


Fig.4.69 Position control system exploded view

		Component description		P/N	General dimensions	Material	Mass	CAD DATA
1.6	Position Control			S160				S_POSITION_CONTROL.prt
		1.6.1	Arduino Leonardo	C161	53X68x13	PCB		ARDUINO_LEONARDO.prt
		1.6.2	X2 Screw M10X3	C162	M3X10	Steel		SCREW_M3X10.prt
		1.6.3	Electric cable green	C163	-	-		ELECTRIC_CABLE_GREEN.prt
		1.6.4	Electric cable black	C164	-	-		ELECTRIC_CABLE_BLACK.prt
		1.6.5	Electric cable red	C165	-	-		ELECTRIC_CABLE_RED.prt
		1.6.6	Potentiometer	C166	Ø6X57	Steel		POTENTIOMETER.prt
		1.6.7	GEAR	C167	27Ø15	Steel		GEAR.prt
		1.6.8	Rubber washer	C168	M5x20	Steel		RUB._WASH_POT.pprt

FUNCTIONALITY

Adjust friction against the axis, so the user can adjust to his preferences the amount of force needed to move the lever

TARGET PERFORMANCE

Smooth friction, adjustable with one hand, easy to operate

DESIGN REQUIREMENTS

DURABILITY

By durability point of view. Needs to be compact, strong and stable to provide robust feeling & functionality

FESEABILITY

Prototype it is made with a Prusa 3D printer, the design is made thinking in the constrains of this productive method.

WORKABILITY AND SERVICEABILITY

The assembly or disassembly of the component has to be allowed during the life of the product.

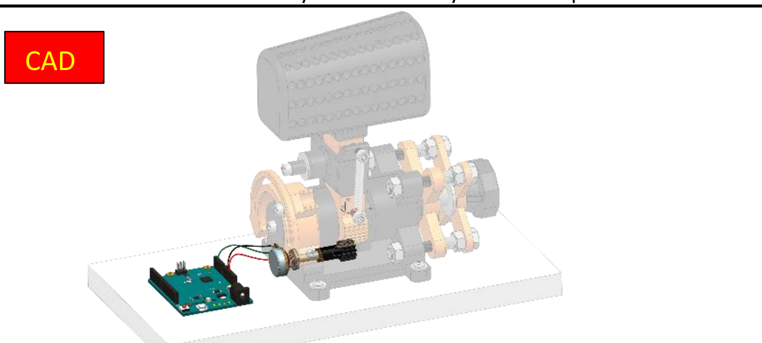


Fig.4.70 Position control system situation

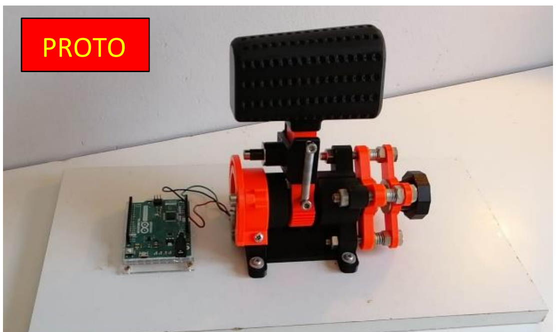
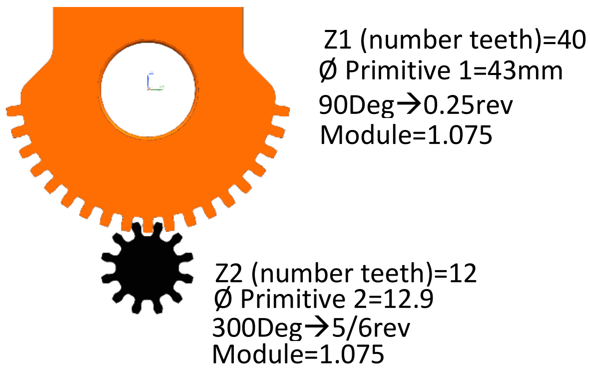


Fig.4.3 Throttle proto image

4.6.11 System S160 (CONTROL POSITION) design explanation



$$Z2 * \frac{5}{6} revolution = Z1 * 0.25 revolution$$

$$12 * \frac{5}{6} = 40 * 0.25 \rightarrow 10$$

Fig.4.71 Gears operability

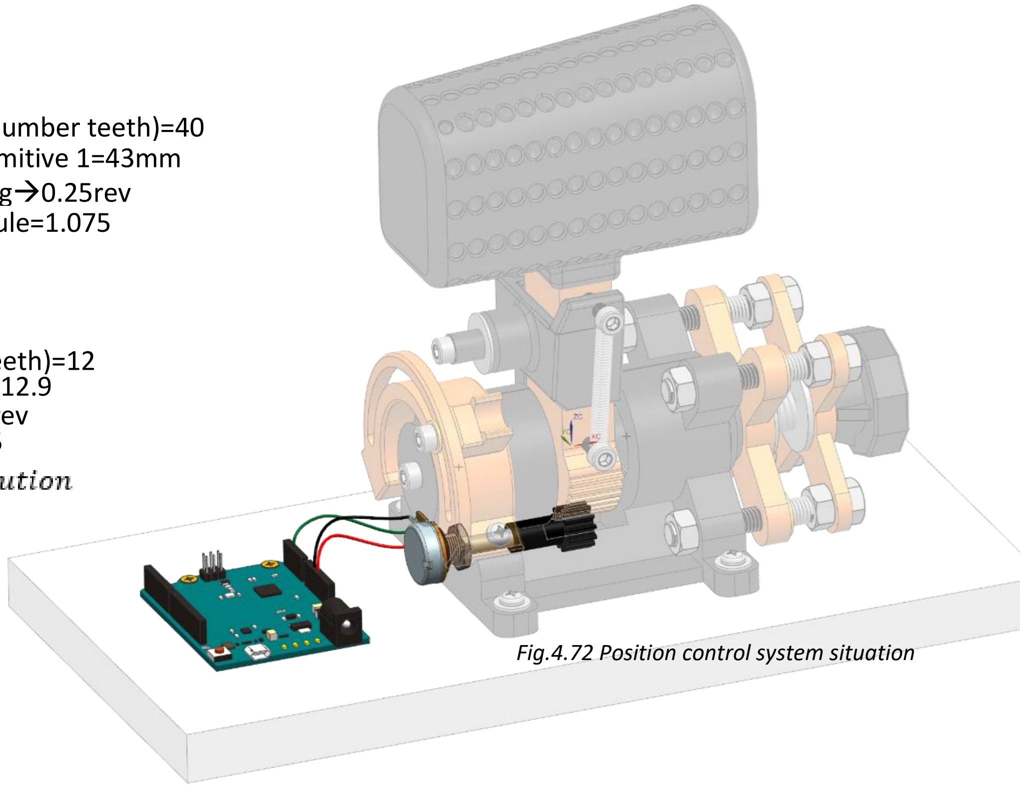


Fig.4.72 Position control system situation

Control position system provides a way to define in which position is the lever at any time.

That information needs to be transmitted and be understood for the PC windows environment, for being used in any flight simulator on the market.

To achieve that the lever transmits their position mechanically with a mechanism of gears.

The bottom of the lever finish with a gear part. his part interacts with another gear (C167) fixed on the potentiometer (C166). So, the movement of the lever is transmitted to the gear(C167) on the potentiometer. The position is in first step transmitted mechanically and then transformed on a signal of voltage for the potentiometer.

As the potentiometer has a rotation of 300 degrees and the lever 90 degrees, it wants to make a mechanical connection that achieve for 90 degrees of the lever→ 300 degrees on the potentiometer to have the maximum resolution (fig.4.71).

It uses a multiplier mechanism of gears (fig.4.71) 1=motor wheel, 2= driven wheel.

The potentiometer is fixed to the Body with a nut (C169) and a washer (168), the analogic signal of the potentiometer needs to be transformed to a digital protocol for windows work.

This protocol is (HID) (Human Interface Device), which will be driven by Microsoft between the USB device and the objective of establishing specifications that allow the development of compatible drivers with computers.

To transform the analogue signal (voltage) to a digital signal protocol (HID) is used an Arduino (C161) Leonardo board.

Why Arduino?

Arduino is a prototype development board that incorporates hardware that allows you to treat analog and digital inputs. For the command, it will be necessary to convert the voltage variations of a potentiometer that would connect to the throttle to digitalized information that must be sent to the Computer.

On the other hand, another decisive element for the decision to use Arduino is the fact that there are already developed and proven libraries that implement the USB_HID protocol.

Let's say, if we take advantage of the analog / digital conversion capability and the ability to communicate via USB-HID, we can easily connect our command to a PC where there is a simulator that supports peripherals with the HID standard.

Which model?

The chosen model is Arduino Leonardo, because the library "Arduino Joystick Library" that allows you to program USB-HID dispositive, only works with the ATmega32u4 processor that is the one that Leonardo has.

→Electric sketch

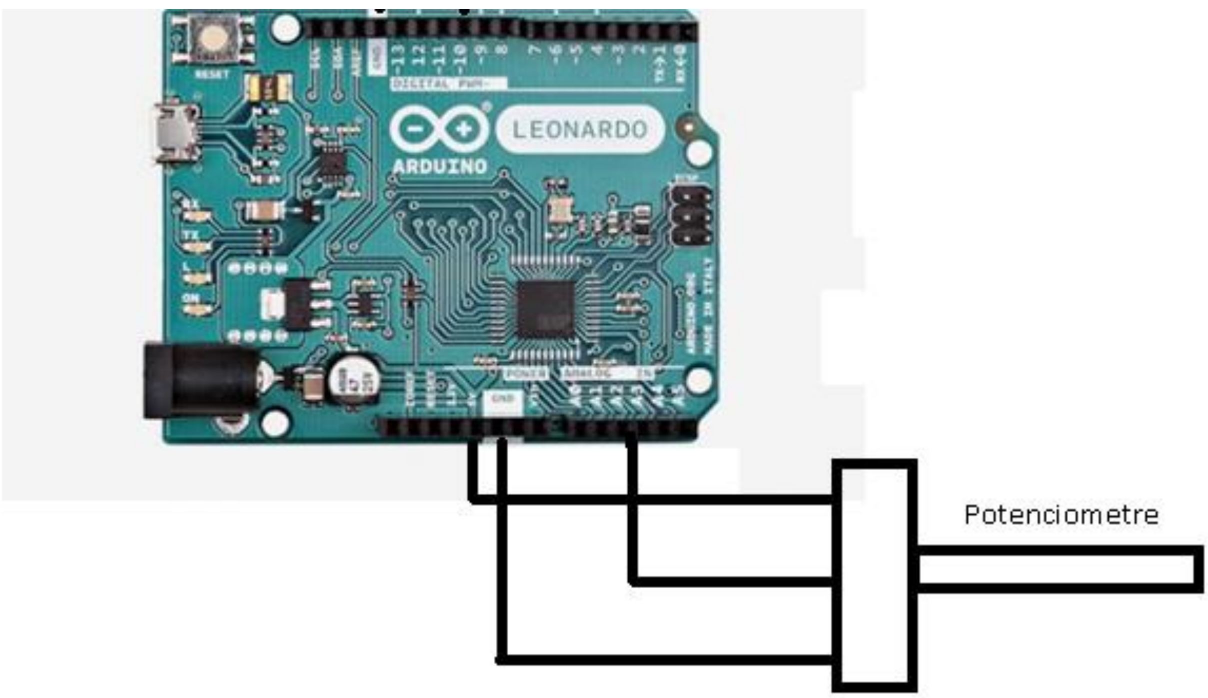


Fig.4.73 Arduino and potentiometer electric sketch

→Code

```
// Pin A3 = Y Axis

// Pin 16 = Button 1
//-------------------------------------------------------------

#include "Joystick.h"

Joystick_ Joystick(JOYSTICK_DEFAULT_REPORT_ID,JOYSTICK_TYPE_JOYSTICK, 2, 0,
false, true, false , false, false, false, false, false, false, false, false);

void setup() {
pinMode(A3, INPUT);
pinMode(16, INPUT_PULLUP);
Joystick.begin();
}
void loop() {
// Y-Axis
        int yAxis = analogRead(A3);
        Joystick.setYAxis(yAxis);
// Button 1
        int button1State = !digitalRead(16);
        if (button1State == 1)
        { Joystick.pressButton(0);}
        else { Joystick.releaseButton(0);}
delay(50);
}
```

Fig.4.74 "Arduino joystick library "code

→PC connection via USB

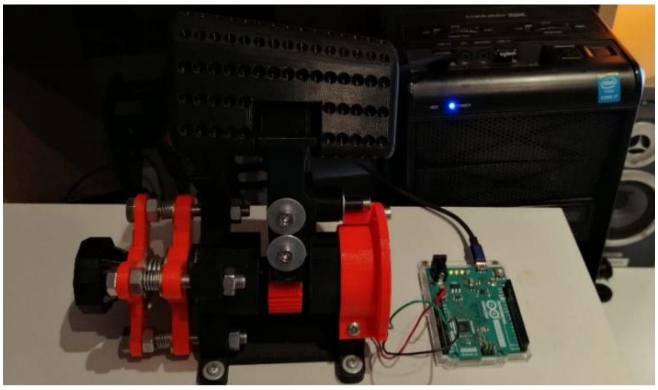


Fig.4.75 Throttle prototype connected to a pc via USB

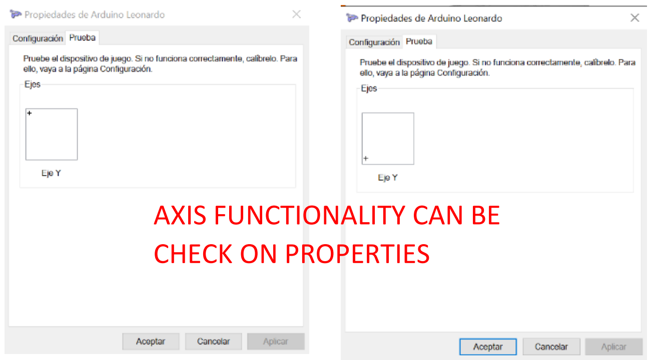


Fig.4.76 Device properties (axis operation can be checked)

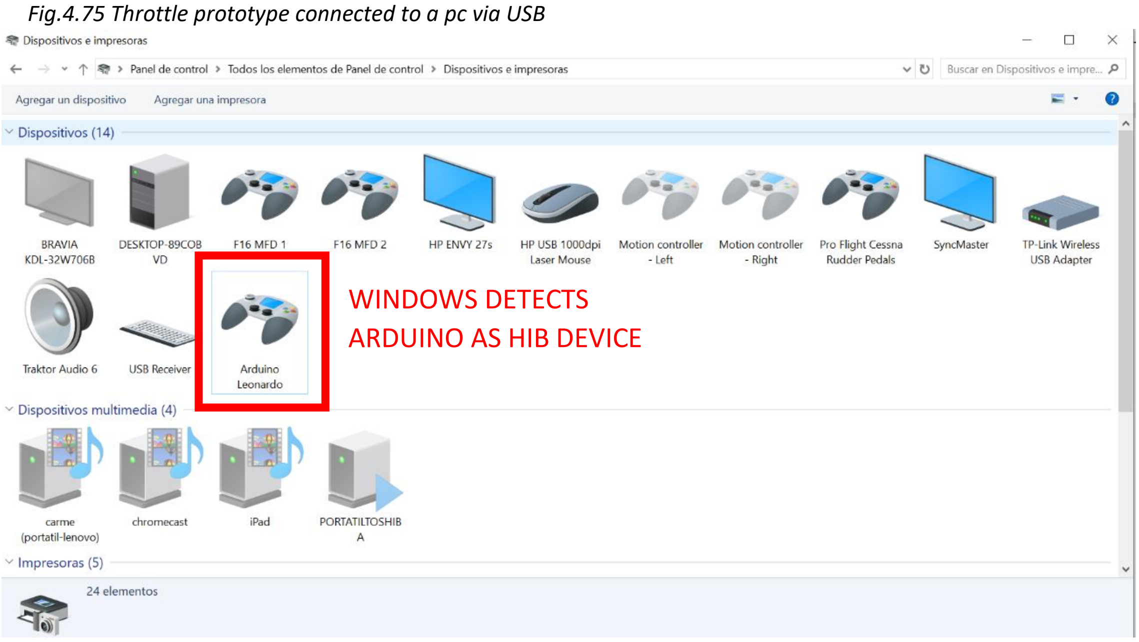


Fig.4.77 Control panel device view, windows detect Arduino as HIB device

4.6.2 Component C167 Gear development sheet

REF	P/N	DESCRIPTION
1.6.7	C167	Gear

GEOMETRY OVERVIEW

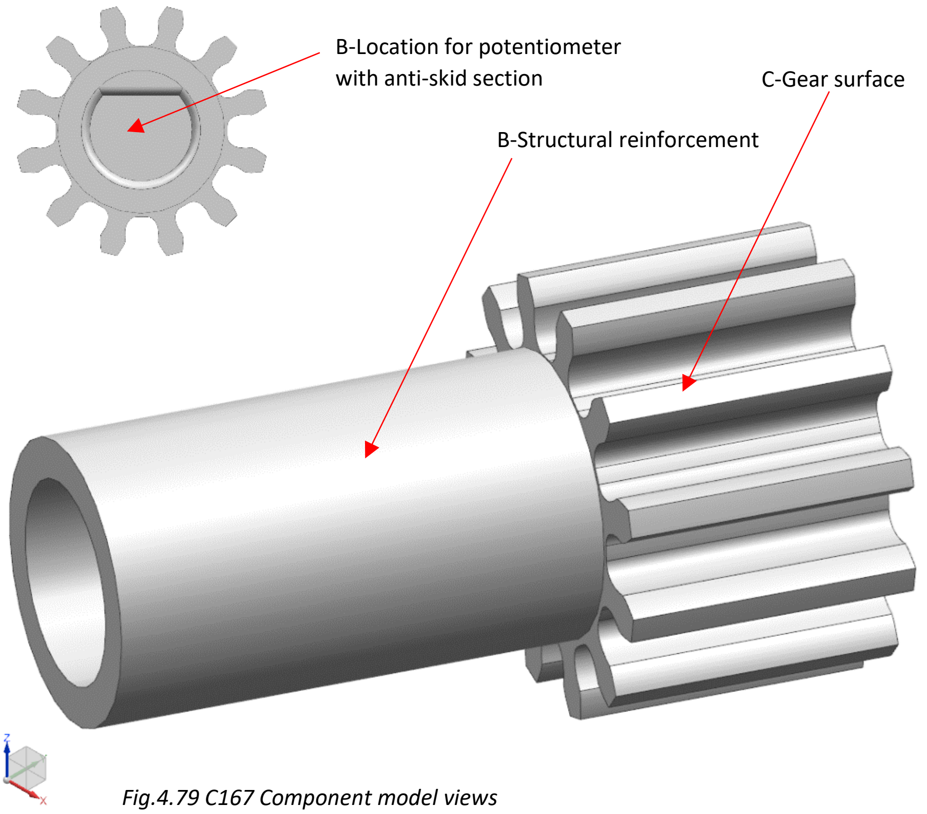


Fig.4.79 C167 Component model views

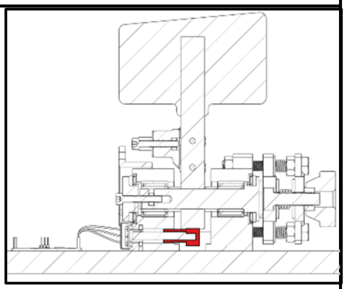


Fig.4.78 Component C167 situation

LEGACY DESIGN

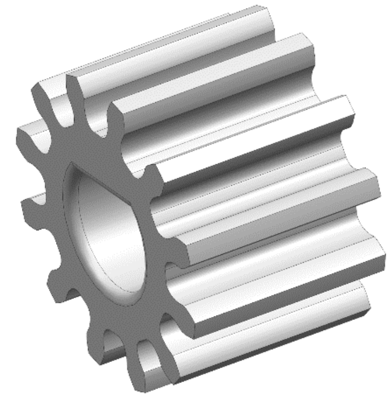


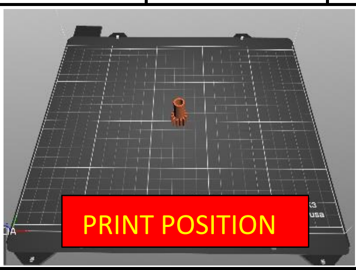
Fig.4.80 C167 legacy design

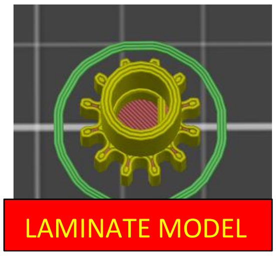
FUNCTIONALITY
Transmit the movement of the lever to the potentiomete with the maximum resolution.

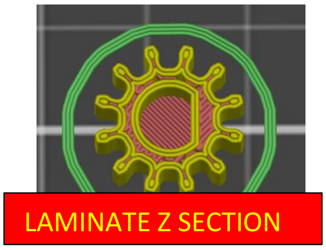
RELEVANT DESIGN ITEMS	
A	Location for the end of the potentiometer with anti-skid section
B	Structural reinforcement in form of cylinder for less allowable movement of the potentiometer causing disconnections through the gears
C	Gear surface to rotate the potentiometer with the transmitting position from the lever gear

PROTO MANUFACTURE PARAMETERS						MATERIAL COLOR: BLACK
3D printer model	MATERIAL	QUALITY	FILLING	BASES	STL DATA	GCODE DATA
PRUSA MK3	PET G	0.15mm	20%	NO	GEAR.stl	GEAR.gcode

POS.		ROTATION
X	0	0
Y	0	-90
Z	0	0







TEST	JUDGMENT	DESCRIPTION	C/M	C/M JUDGMENT
ALL	NG	Gears diconection	Put cilinder to make strucure more rigid Avoiding potentiometer vibrations	OK

Fig.4.81 C167 Component Prusa 3D printer model views (position, laminate model, laminate section)

5. Other information

Component	System	Estimated printing time
Axis	S120 Axis	205min
Body	S100 Stand	331min
Brake	S130 Friction regulation	65min
Brake bedplate	S130 Friction regulation	47min
Brake wheel	S130 Friction regulation	58min
Cap axis	S120 Axis	21min
FD lever	S140 Flight detents	157 min
Gear	S160 Position control	33 min
Lever	S120 Axis	111 min
Top axis	S120 Axis	31min
FD support guide	S140 Flight detents	77 min
FD cut off	S140 Flight detents	33 min
Grip	S150 Grip	383min

Fig.5.1 Estimated printing time by Prusa 3D printer

TOTAL=25hours

CAD FILES STRUCTURE

	_NKI 15_20_PART1.prt	24/05/2019 19:14	Siemens Part File	84 KB
	_NKI 15_20_PART2.prt	24/05/2019 19:14	Siemens Part File	85 KB
	_NKI 15_20_PART3.prt	24/05/2019 19:14	Siemens Part File	71 KB
	_NKI 15_20_PART4.prt	24/05/2019 19:14	Siemens Part File	57 KB
	ARDUINO_LEONARDO.prt	20/05/2019 20:14	Siemens Part File	878 KB
	AXIAL_BEARING.prt	21/05/2019 22:01	Siemens Part File	328 KB
	AXIS.prt	20/05/2019 19:28	Siemens Part File	125 KB
	BODY.prt	24/05/2019 18:34	Siemens Part File	294 KB
	BOLT_M5X15.prt	21/05/2019 19:54	Siemens Part File	917 KB
	BOLT_M5X30.prt	21/05/2019 20:10	Siemens Part File	1.002 KB
	BOLT_M10X35.prt	28/05/2019 19:06	Siemens Part File	964 KB
	BRAKE DISC.prt	20/05/2019 19:47	Siemens Part File	92 KB
	BRAKE.prt	20/05/2019 19:49	Siemens Part File	138 KB
	BRAKE_BEDPLATE.prt	20/05/2019 19:53	Siemens Part File	147 KB
	BRAKE_WHEEL.prt	20/05/2019 20:50	Siemens Part File	180 KB
	CAP_AXIS.prt	20/05/2019 19:35	Siemens Part File	121 KB
	CAP_M5.prt	20/05/2019 20:43	Siemens Part File	92 KB
	ELECTRIC_CABLE_BLACK.prt	25/05/2019 18:39	Siemens Part File	129 KB
	ELECTRIC_CABLE_GREEN.prt	25/05/2019 18:39	Siemens Part File	134 KB
	ELECTRIC_CABLE_RED.prt	25/05/2019 18:39	Siemens Part File	132 KB
	FD_CUT_OFF.prt	20/05/2019 20:40	Siemens Part File	139 KB
	FD_LEVER.prt	20/05/2019 19:25	Siemens Part File	434 KB
	FD_SUPPORT_GUIDE.prt	20/05/2019 20:02	Siemens Part File	243 KB
	FLOOR_PLATE.prt	25/05/2019 18:44	Siemens Part File	91 KB
	GEAR.prt	25/05/2019 16:56	Siemens Part File	266 KB
	JAIL_AXIS_BEARING.prt	21/05/2019 21:53	Siemens Part File	145 KB
	LEVER.prt	20/05/2019 19:23	Siemens Part File	315 KB
	NUT_M5.prt	21/05/2019 20:46	Siemens Part File	408 KB
	NUT_M8.prt	21/05/2019 20:47	Siemens Part File	417 KB
	NUT_M10.prt	21/05/2019 20:44	Siemens Part File	420 KB
	POTENTIOMETER.prt	25/05/2019 17:47	Siemens Part File	915 KB
	RADIAL_BEARING.prt	24/05/2019 19:32	Siemens Part File	92 KB
	RUBBER_WASHER_POTENTIOMETER.prt	25/05/2019 14:16	Siemens Part File	97 KB
	S_AXIS.prt	25/05/2019 19:00	Siemens Part File	109 KB
	S_FLIGHT_DETENTS.prt	25/05/2019 19:14	Siemens Part File	118 KB
Systems	S_FRICTION_REGULATION.prt	25/05/2019 18:53	Siemens Part File	124 KB
	S_POSITION_CONTROL.prt	25/05/2019 19:20	Siemens Part File	94 KB
	S_STAND.prt	25/05/2019 19:14	Siemens Part File	94 KB
	SCREW_M3X10.prt	25/05/2019 19:19	Siemens Part File	637 KB
	SCREW_M5X20.prt	25/05/2019 19:12	Siemens Part File	939 KB
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	SPRING_M8.prt	25/05/2019 14:36	Siemens Part File	419 KB
	SPRING_M10.prt	25/05/2019 11:33	Siemens Part File	324 KB
	THROTTLE_ASSEMBLY.prt	20/06/2019 20:38	Siemens Part File	319 KB
	TOP_AXIS.prt	20/05/2019 19:37	Siemens Part File	117 KB
	WASHER_AXIAL_BEARING.prt	20/05/2019 19:41	Siemens Part File	101 KB
	WASHER_M5.prt	20/05/2019 20:46	Siemens Part File	97 KB
	WASHER_M5_MEDIUM.prt	25/05/2019 14:31	Siemens Part File	100 KB
	WASHER_M5_SMALL.prt	21/05/2019 20:58	Siemens Part File	102 KB
	WASHER_M10.prt	21/05/2019 20:54	Siemens Part File	98 KB
	WASHER_POTENTIOMETER.prt	25/05/2019 13:42	Siemens Part File	270 KB
	WASHER_SCREW_BASE.prt	21/05/2019 21:04	Siemens Part File	102 KB

Fig.5.2 Cad files structure

6. User Product characteristics

→FLIGHT DETENT LEVER WITH SPRING RETURN

Fig.6.1 FD Lever operability image

→SMOOTH MOVEMENT (BEARING CONTROLL) SINCE 90 DEG

→REGULABLE FRICTION

→PLUG AND PLAY

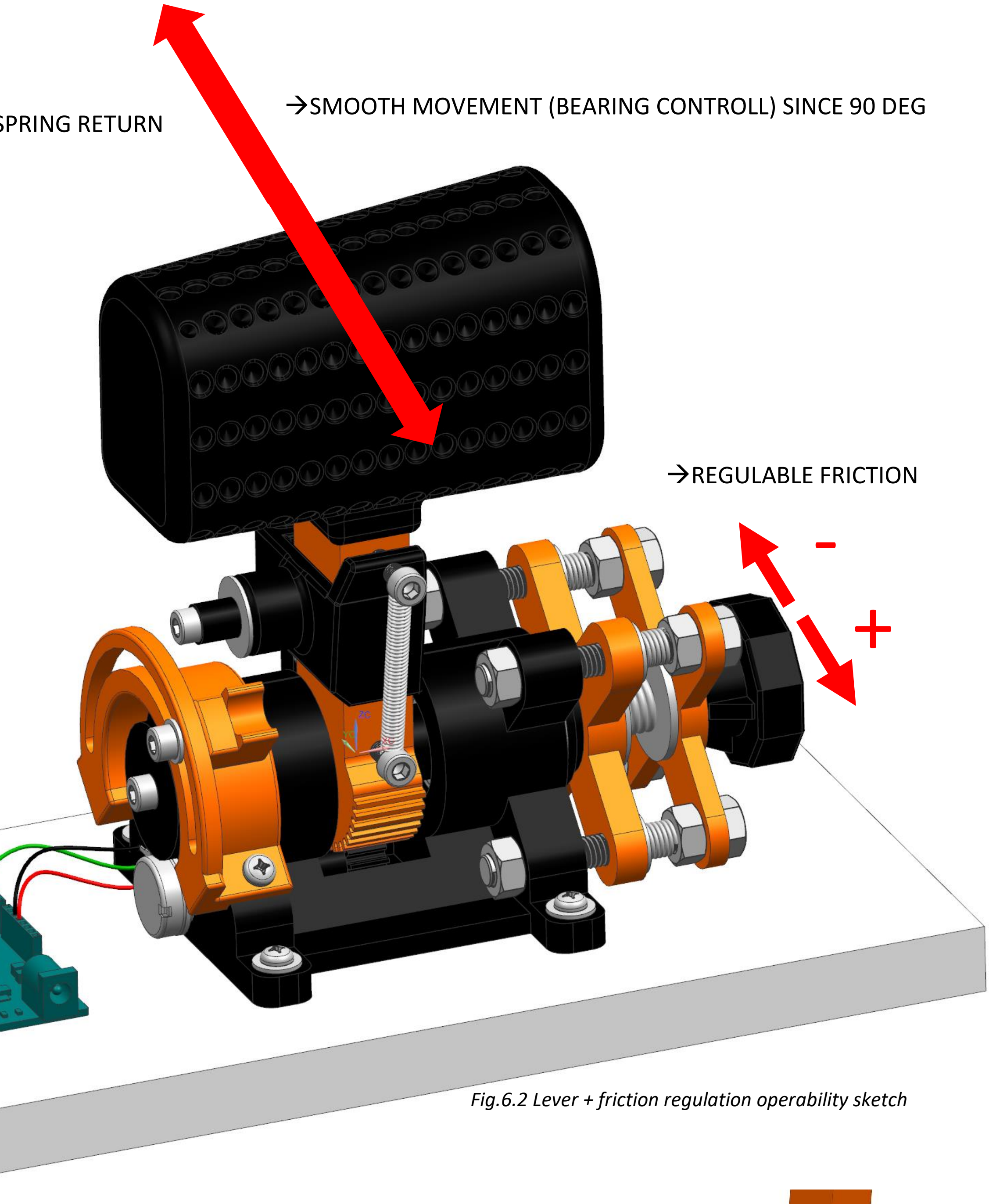

Fig.6.2 Lever + friction regulation operability sketch

→REGULABLE FLIGHT DETENTS (180DEG) IDLE +CUTT OF

Fig.6.3 Flight detents operability sketch

→HIGH AXIS RESOLUTION

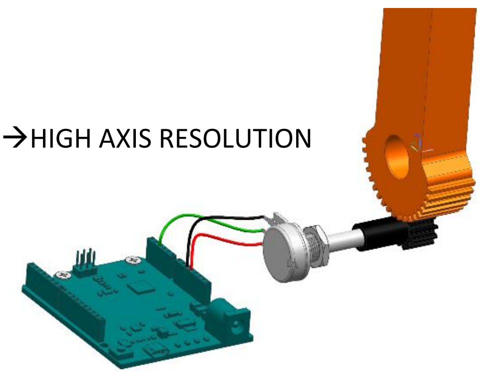

Fig.6.4 Position control operability sketch

7. Cad vs Proto comparison

Fig.7.1 Throttle 3D model right side view

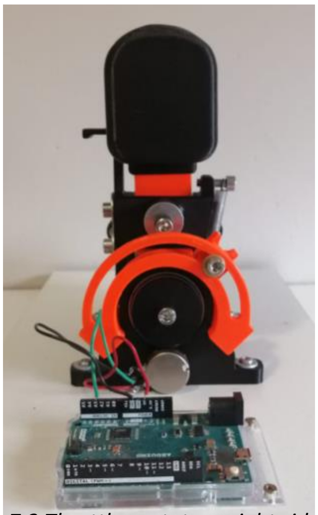

Fig.7.2 Throttle prototype right side view

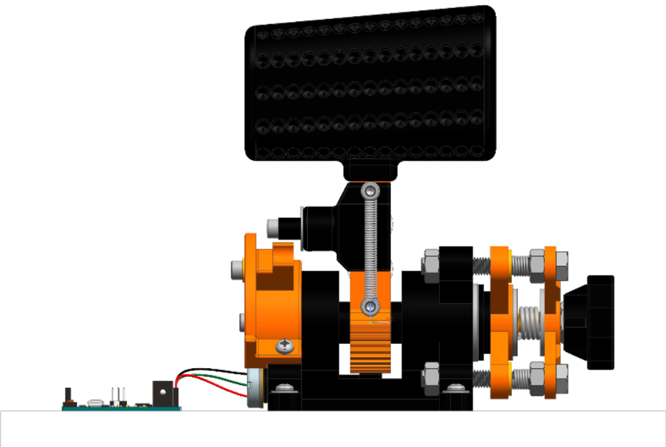

Fig.7.3 Throttle 3D model Front side view

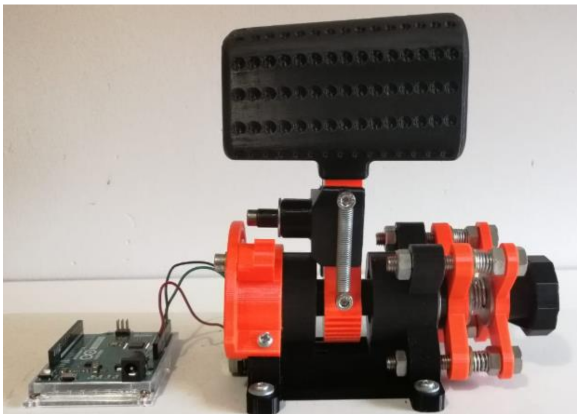

Fig.7.4 Throttle prototype Front side view

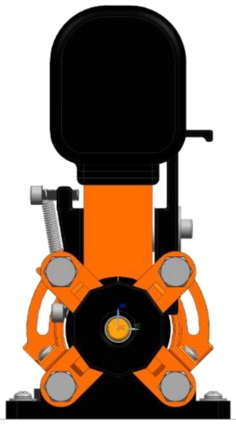

Fig.7.5 Throttle 3D model Left side view

Fig.7.6 Throttle prototype Left side view

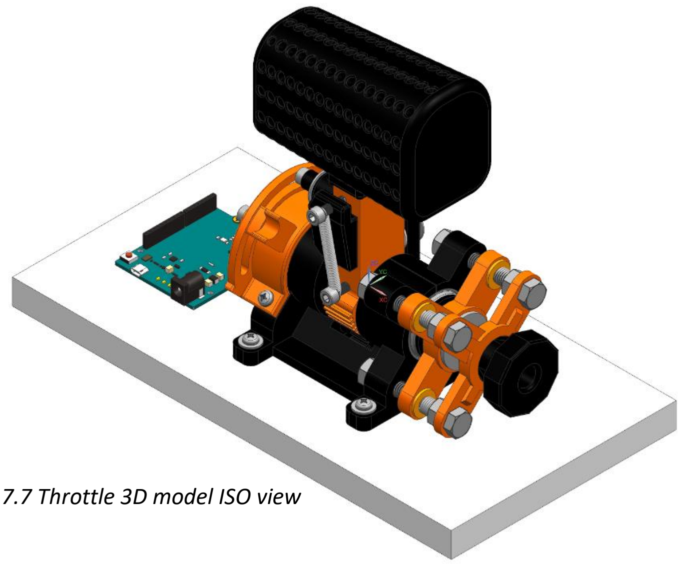

Fig.7.7 Throttle 3D model ISO view

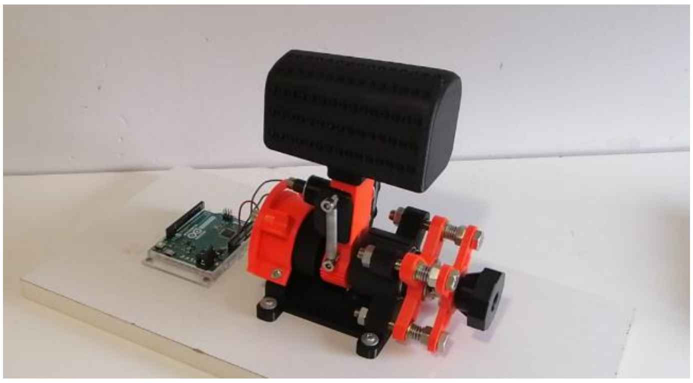

Fig.7.7 Throttle prototype ISO view

8.0 Development of a simulation model for the component C111

8.1 Background

Legacy design for the Body component C111 had a big deformation on X axis (page 22) (fig.8.1) when shaft is assembled, due to that issue a reinforcement was needed to improve stiffness specially in X direction.

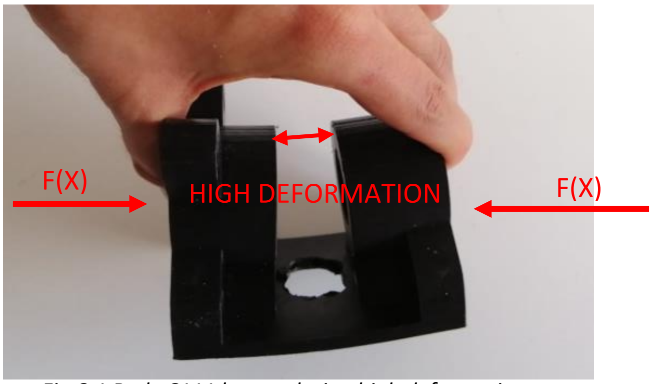

Fig.8.1 Body C111 legacy design high deformation

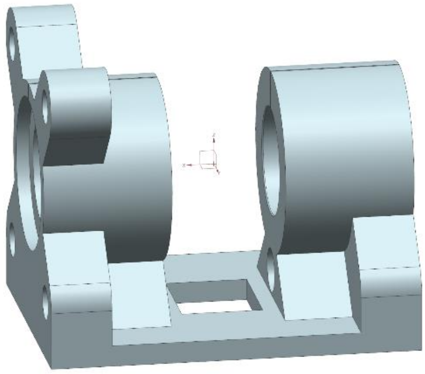

Fig.8.2 Body C111 legacy design

To study structural behaviours, and for the application of countermeasures I decided to develop simulation model that predicts on early stages and future improvements the mechanical behaviour of particular components. That methodology can be exported to the rest of the components, to ensure quality design.

The simulations will predict the 3D printing structural behaviours (with a cell structure defined by filling parameter) (fig 8.3), with a NX CAD model (with solid sections instead cells structures) (fig.8.4).

3D printed structure cells

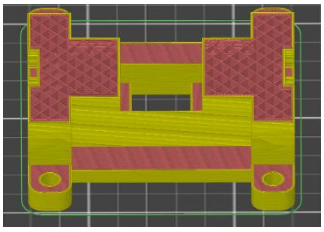

Fig.8.3 Body C111 legacy design 3D printed structure (cells)

NX model solid sections

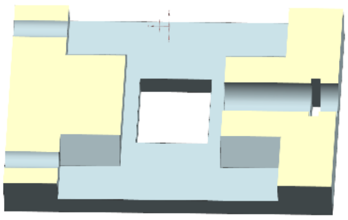

Fig.8.4 Body C111 legacy design 3D Model structure (solid)

→Simulation objectives

1-Obtain the equivalent parameters for the component to develop a simulation as accurate as possible.

2-Use the simulation to understand the behaviour of the component and improve the design.

→Simulation development methodology

<Variables>

1-Yong Module

2-Poisont ratio

PHISICAL TEST

SIMULATION MODEL

<input> F (kgf) → Same input → <input> F (kgf)

<Test Output> Deformation (mm) ↔ <Simulation Output> Deformation (mm)

Output match

Fig.8.5 Methodology for the development of simulation model

8.2 Physical Test

→Test Material

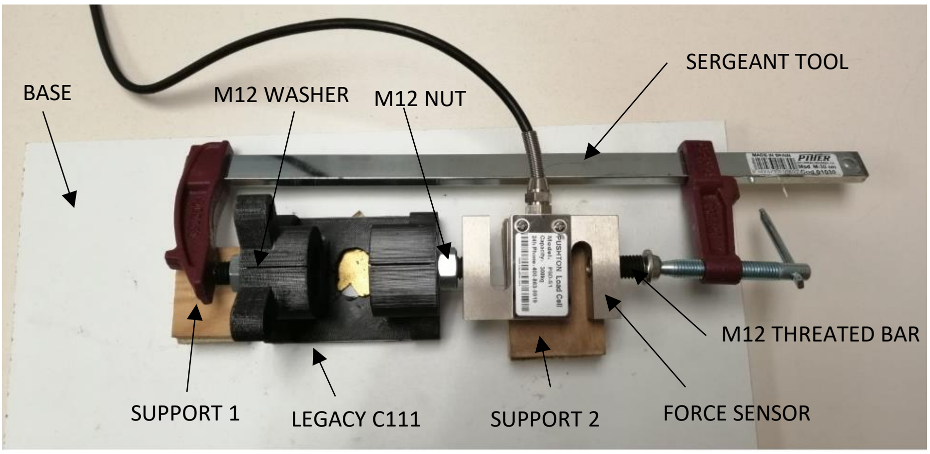

Fig.8.6 Test components and layout

→Test operation

Test consists on apply a compression force with the sergeant tool to the component, on the X axis, simulating the force applied by the shaft, increasing the force and measuring the output distance D Test (mm).

The applied force is measured with the Force sensor via PC, an Arduino convert de analogue data of the strain gauge diode bridge to digital output (fig.8.7).

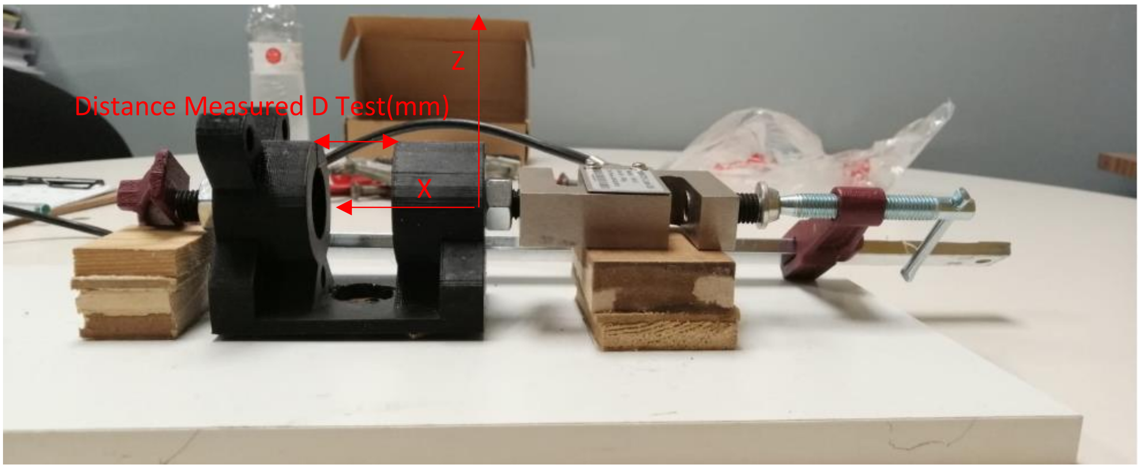

Fig.8.7 Test coordinates and measured distance definition

→Physic Test Results

F(kg)	D Test(mm)	Deformation(mm)
0.4	27.9	0.1
1.61	26.6	1.4
2.2	26	2
2.48	25.5	2.5
2.74	25	3
3.12	24.5	3.5
3.52	24	4
3.8	23.5	4.5
4.22	23	5

Fig.8.8 Physics test results table

Distance measured without load is 28mm.

Fig.8.9 Physical test Stiffness graph

8.3 Simulation Model

→Simulation considerations

1-Simulation will be made on NX-CAE context with finite elements method

2-The solver will be NASTRAN -SOL 101 Linear Statics -Global Constrains

3-Due the simulation time and objective of the simulation, the component will be used with the 3D mesh Cetra 4 with element side of 10 (fig.8.10)

4-This is not a search for the real material properties, the objective is determinate a system to predict behaviours as much close it can to the test results. Due the big and imprecise mesh used Young Module is expected to not be close to the real value of the material.

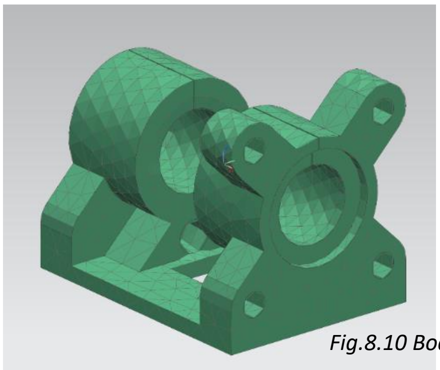

Fig.8.10 Body C111 finite elements mesh (CETRA4) element size 10mm

5-Loads and constrains will be positions as follows simulating the test loads(fig.8.11 & fig.8.12):

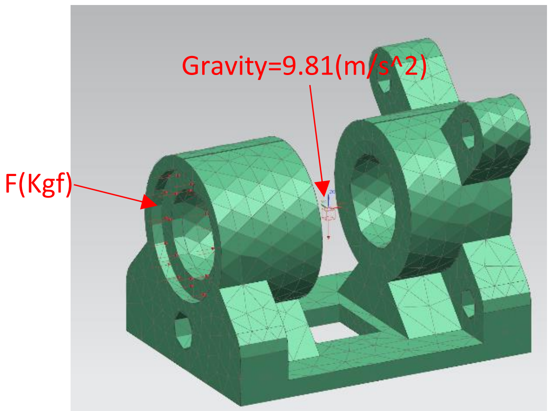

Fig.8.11 Simulation loads definition

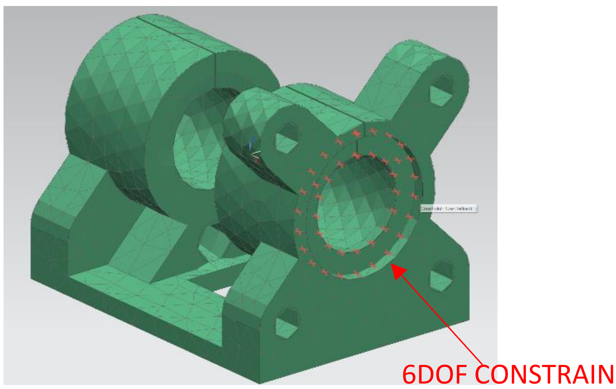

Fig.8.12 Simulation constrains definition

→Simulation assumptions

-The component will act like an isotropic material

→Simulation operation

The development of the simulation model will consist to iterate the properties of the material to achieve with the same Force input the closest distance D output results compared to physical test results.

As it assumes the component acts like isotropic material, the only variables of the iteration are:

-Young Module

-Poison ratio

Other important property needed for the simulation is the equivalent density of the component.

→Calculation of the component density

Equivalent density will be calculated with the following expression:

$$density(kg/mm^3) = \frac{mass(Kg)}{Volume(mm^3)}$$

The component is 3D printed with a filling of 20 %, for that reason mass and volume can't be extracted via CAD data NX, so mass it's extracted with the help of a weighing machine (fig8.14).

-Mass=0.071Kg

Fig.8.13 C111 weight measurement

The volume of the component is obtained by the volume of water displaced by the component (fig.8.14).

-Volume of the component = volume water displaced =150ml→ 150.000mm^3

Fig.8.14 Volume calculation material

Equivalent density is:

$$density\left(\frac{kg}{mm^3}\right) = \frac{mass(Kg)}{Volume(mm^3)} = \frac{0.071kg}{150000mm^3} = 0.000000473\left(\frac{kg}{mm^3}\right)$$

→Parameters Iteration

The simulation will be repeated with the iteration of the Young Module and Poison ratio (fig.8.15) until the achievement of the closest results compared with output physical test with the same force input. Simulation data can be found in the ANNEX B.

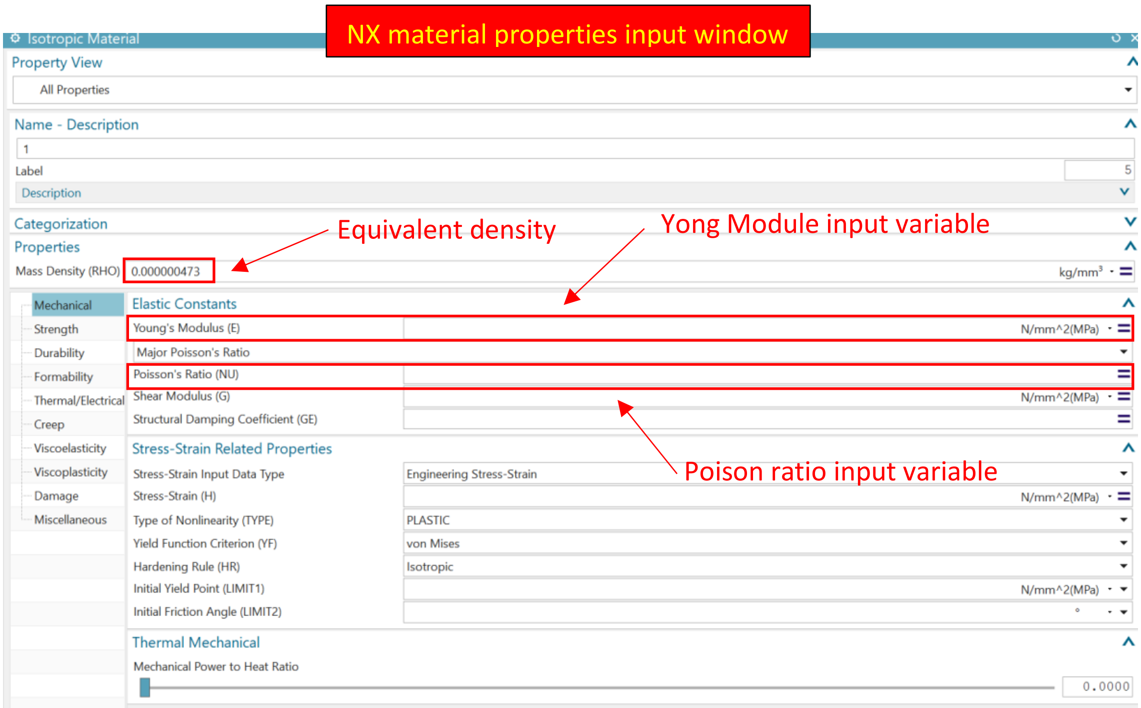

Fig.8.15 NX simulation material properties assignation window

→Output treatment

When NX solves the simulations, the results will be showed as displacement on X (fig.8.17) and Z (fig.8.18) direction (No Y displacement) for each input force, with that information and the following expression Output distance D measured is calculated.

$$D(mm) = \sqrt{(z)^2 + (28 - x)^2}$$

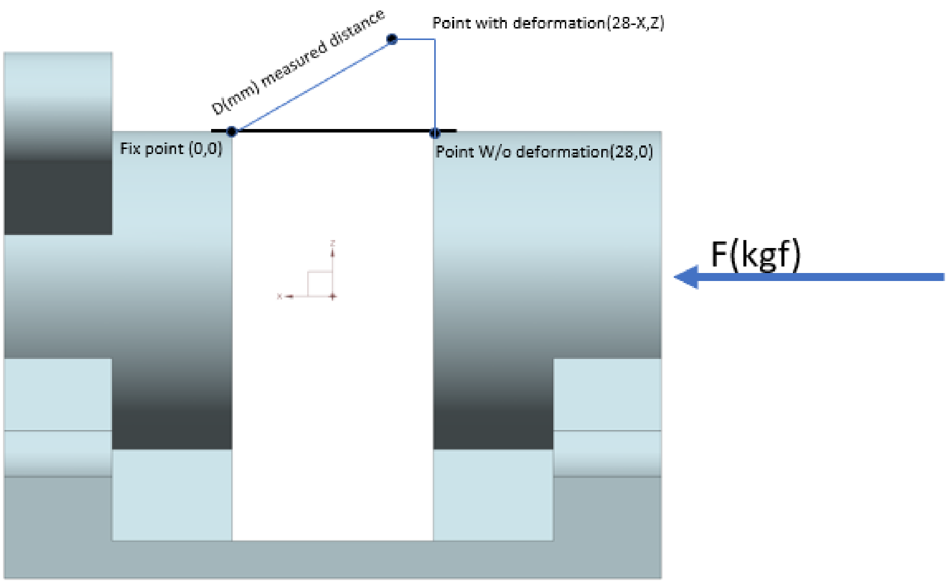

Fig.8.16 Deformation parameters definition

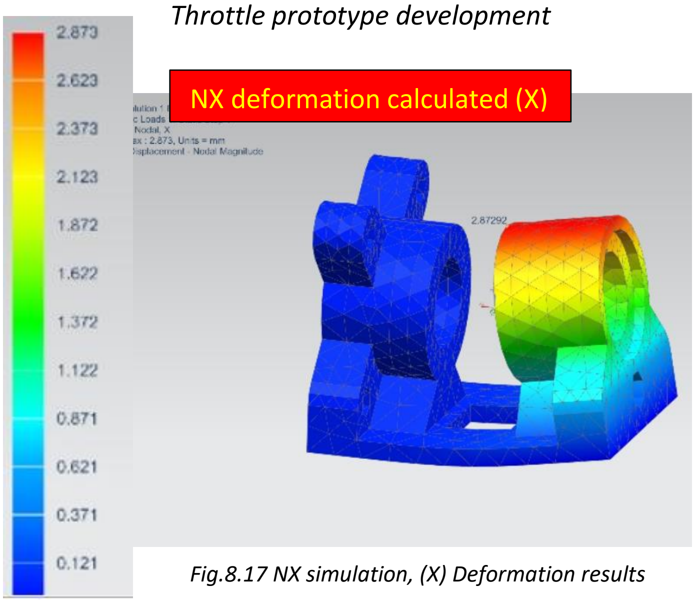

Fig.8.17 NX simulation, (X) Deformation results

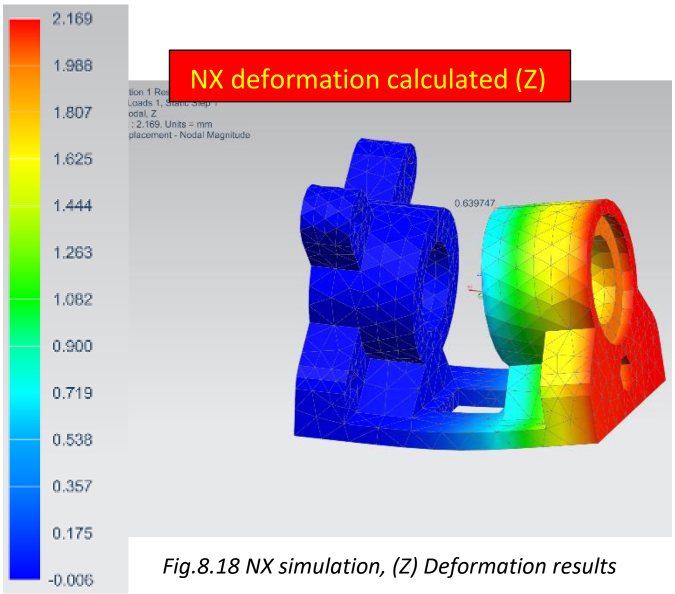

Fig.8.18 NX simulation, (Z) Deformation results

8.4 Results

→Poison evolution impact

1-YOUNG MODULE→CONSTANT 400Mpa
2-POISON RATIO→FROM 0.1 TO 0.4

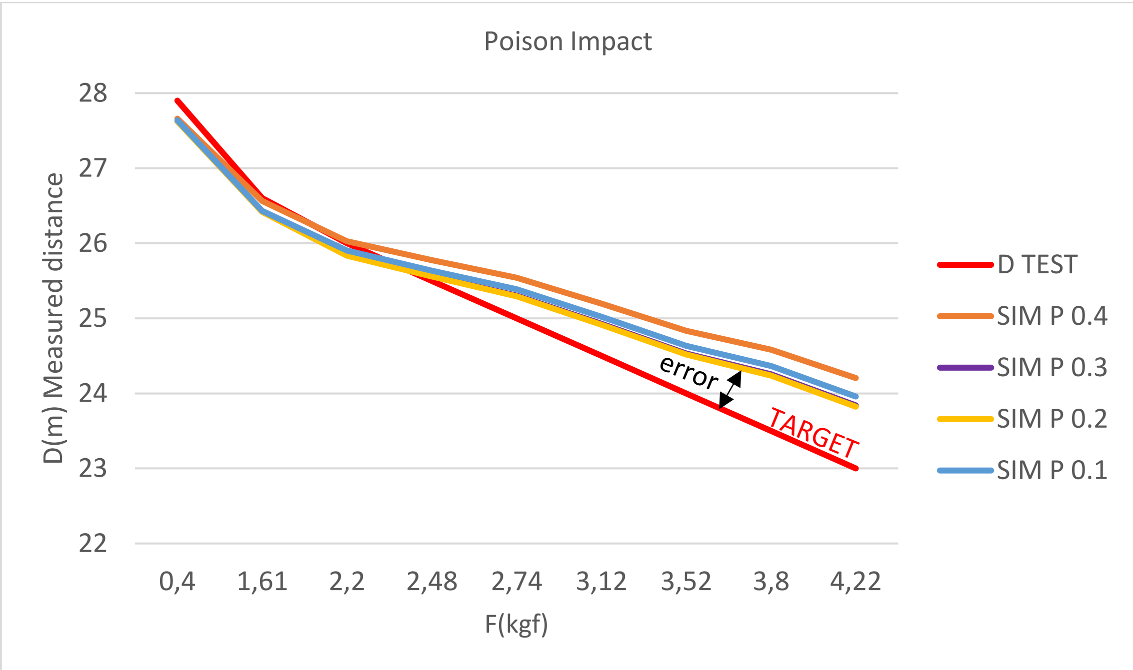

Fig.8.19 Poison impact on measured distance graph

ITEM	AVERAGE ERROR% respect test D(mm)
SIM P 0.4	1,70
SIM P 0.3	1,21
SIM P 0.2	1,19
SIM P 0.1	1,38

Best results Poison 0.2

Fig.8.20 Average error on Poison impact table

<u>Poison Ratio impact conclusions:</u>

-If Poison ratio increases ↑ error respect test also ↑ increases, but if ratio ↓decreases from 0.2 error also ↑increases.

-Poison around 0.2 obtain the most accurate results

→Young module evolution impact

1-YOUNG MODULE→FROM 300Mpa to 450Mpa
2-POISON RATIO→0.2 Constant

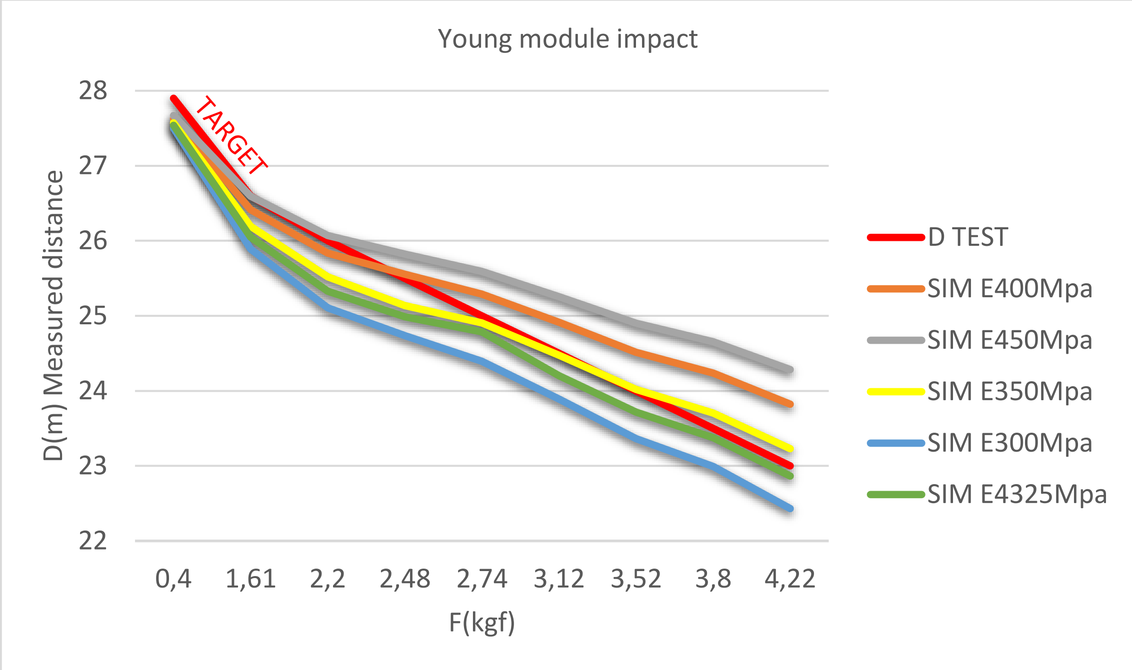

Fig.8.21 Young module impact on measured distance graph

ITEM	AVERAGE ERROR% respect test D (mm)
SIM E450 Mpa	1,83
SIM E400 Mpa	1,19
SIM E350 Mpa	0,96
SIM E325 Mpa	1,30
SIM E300 Mpa	2,25

Best results Young 350Mpa

Fig.8.20 Average error on Young module impact table

Fig.8.22 deformation comparison graph (test vs E350 P0.2)

Young module impact conclusions:

-As Young moves away from 350 Mpa error increases

-On 350Mpa, when more force is applied more precise is the model, less error

-350Mpa gives the more accurate results

8.5 Simulation model final conclusions

The most accurate model is achieved with a Young module of 350Mpa and a Poison ratio of 0.2. The results are very good with a little error basically when little force, less than 2.74Kg is applied.

This error can be from the measurements in the Physic test due a human error, sensitivity of the machine and others factors and it is negligible, in general terms, is a very accurate model.

The calculated properties of the model are not the material properties, are only variables to ensure the precision of the mathematical model, this is because the extra solid material from the NX CAD instead the real quantity of material from the 3D printed (20% cells), and the low accuracy of the mesh with Cetra 4 with a big element size of 10mm.

With the model now is possible to study the component and quantitatively with no physical object, know the behaviour, and study design modification.

→C/M results

To improve stiffens and have less deformation C/M reinforcement was applied at the bottom of the piece, now with the model without physical component can it know how is the improvement of this reinforcement.

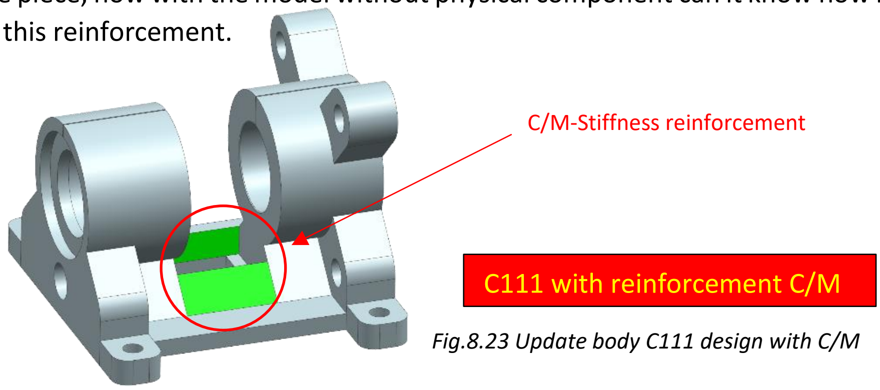

Fig.8.23 Update body C111 design with C/M

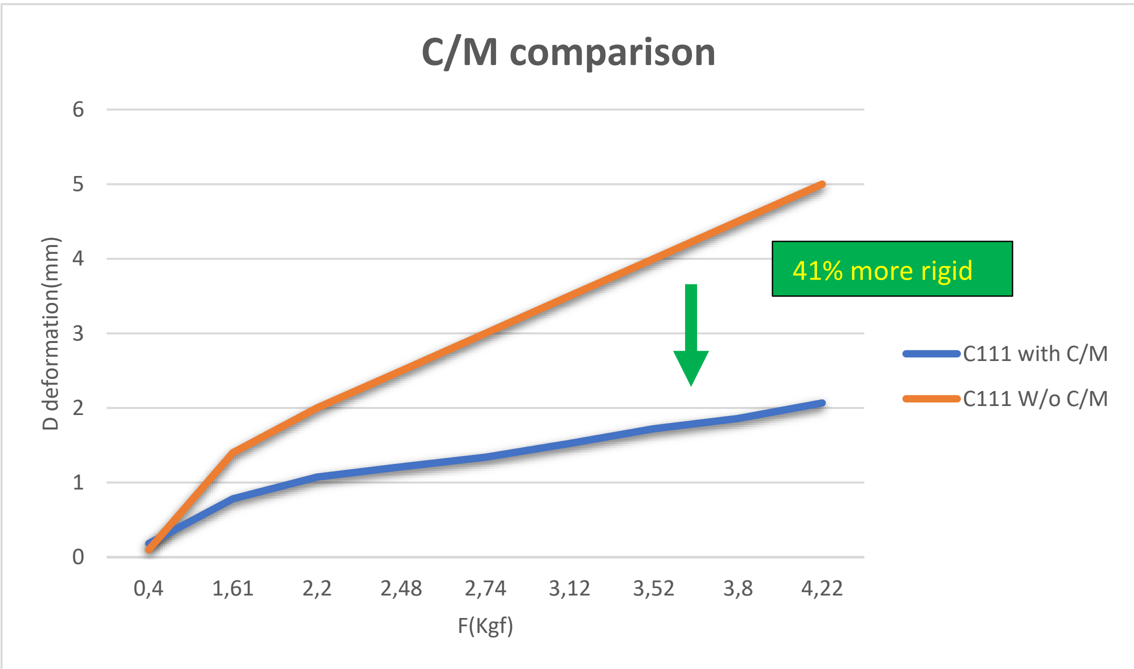

Fig.8.24 Deformation comparison (legacy design vs C/M design)

<u>C/M conclusions:</u>

-The component with the C/M is average 41% more rigid than the legacy design

9.Project conclusions

The development of the throttle for simulation aviation has been a success, with improved characteristic compared to direct rivals.

With the use of rolling bearings, very smooth movement is achieved compared to the most standard lubricated axis.

An easy friction regulation provides the amount of force required for any user, its ease use with only one hand and no tool required, puts it one step ahead of its competitors.

I selected this project because of my passion of planes world. It has been a large time of planning, study and work but it allowed me to go deeper and better understanding how a throttle works. But the most important thing is that it teaches me to how to develop a project from the scratch by my own. I applied a lot of knowledge that I learnt in the university and my professional work.

It has been a large way where every issue that was appearing it was analysed and solved every time. This made me be more analytic and improved my skills and enginery knowledge. The final prototype has reached most of the objectives becoming a solid product.

Analysing the product using the simulation process that I mentioned in this project we can get better version.

The simulation model developed has exceeded my expectations, being very close to the real component behaviour.

Now with that model, and using the same methodology, every plastic component can be analysed and improved before printing and testing.

10.Agradecimientos

Quiero agradecer a mi familia todo su apoyo durante todos estos años, nunca dudando en que podría alcanzar mis metas.

A mi director de proyecto el Dr. en Ingeniería Industrial Hernan A- Gonzalez por su apoyo y guía en la realización de este proyecto.

Por último, a la gente de Nissan technical center Europe por ayudarme a crecer como ingeniero y diseñador.

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Annex A: Prototype drawings

Annex B: Simulation raw data